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NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

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## STUDY OF EQUIPMENT AND METHODS FOR REMOVING OR DISPERSING OIL FROM OPEN WATERS

August 1970



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## STUDY OF EQUIPMENT AND METHODS FOR REMOVING OR DISPERSING OIL FROM OPEN WATERS


### ABSTRACT

A cost effectiveness analysis was performed for equipment, materials and techniques applicable to the removal or dispersal of spilled oil from U.S. Navy AO and AOG vessels on open waters. Effectiveness parameters included oil product types (JP-5, Distillate Fuel, Navy Special and Bunker C), a range of spill locations (3 and 12 miles from shore) and varying spill sizes (2,700 gal, 270,000 gal, and 6,750,000 gal). Criteria for evaluation of systems under the above parameter situations, formulated for presently available equipment and materials, included: completeness of oil removal; rate of removal; hazard and pollution; use in limited access areas; sensitivity to expected environmental factors; sensitivity to temperature extremes; toxicity to marine life, and system availability. Cost effectiveness was determined using the 3 spill sizes and checked for spill frequency sensitivity. The three most cost effective systems for the range of spill sizes were found to be burning, dispersing, and mechanical skimming. Considering system applicability to various products and the requirements of rate of removal for massive spills, the most practical universal system with a favorable cost effectiveness ratio was found to be dispersing. This is followed by dispersing plus a containment boom. Burning agents applied directly to the spill were judged to be the third best system based on its favorable cost effectiveness but limited applicability to oil types and permissible burning circumstances.

# FOREWORD

This report summarizes research conducted by Battelle-Northwest for the U.S. Department of the Navy, Naval Civil Engineering Laboratory, under Contract: No. N62399-70-C-0008.

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|---|---|
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Acknowledgement must also be given to the cooperation and assistance provided by the many interested parties. Special thanks go to personnel of Naval Ships Systems Command, and many manufacturers of commercial equipment and materials in providing the data for this report.

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SYNOPSIS OF NCEL CR71.001 - STUDY OF EQUIPMENT AND METHODS FOR REMOVING OR DISPERSING OIL FROM OPEN WATERS* (Contract N62399-70-C-0008)

21 September 1970

N. S. Stehle

## INTRODUCTION

Many types of equipment, materials and techniques have been employed to remove spilled oil from open waters; because of the wide range of conditions and petroleum products possible, no single system is likely to be completely effective. This study was made to identify and describe the open sea conditions under which a Navy AO or AOG vessel would need a capability to combat an oil spill, and to identify the most cost-effective systems consisting of available or new combinations of existing equipment, materials and techniques.

## OIL SPILL TREATMENT

Three operations are involved in oil spill treatment: containment, removal, and disposal.

### Containment (pp 22-26, D-1 to D-17)**

The containment boom is used to control and thicken the oil; it may, however, present a barrier to equipment and vessels. When the slick is not moving with the wind or current, complete encirclement is necessary in order to prevent thinning of the oil. When it is moving with the wind or current, the boom can be placed in a catenary shape directly opposing and downcurrent of the moving slick. Containment barriers are divided into floating booms, pneumatic (air) barriers, chemical barriers, and powered booms.

*Prepared by Pacific Northwest Laboratories, a division of Battelle Memorial Institute, Richland, Washington, 1970.

**Page numbers refer to pages with additional information in NCEL CR71.001, "Study of Equipment and Methods for Removing or Dispersing Oil from Open Waters," August 1970.

Floating Booms. (pp 23-25) A floating boom must provide a vertical barrier both above and below the water surface. The boom is commonly formed by combining a buoyant section with a skirt of metal, plastic sheet, or rubberized fabric with lead weights or steel chain as ballast on the bottom edge. Skirts of extended draft are necessary in the presence of surface currents to impede the oil from being swept under the boom. Tests with a boom having an 8-inch-diameter buoyant section and 3-foot skirt showed that oil would escape in a one knot current and waves greater than 6 inches. For a boom to be effective, it must be flexible so it can follow the water surface, and yet have sufficient strength to be towed or permanently moored. Floating booms using air-filled chambers for buoyancy are generally not satisfactory as they can be punctured resulting in loss of buoyancy.

Pneumatic Barriers. (p. 25) Pneumatic, or air, barriers operate by injecting air through a perforated hose or pipe into the water from a depth sufficient to permit passage of ships. The bubbles rise creating a surface current flow in both directions away from the line of air emergence. Because they must be custom-designed for each application, pneumatic barriers are generally permanently installed. Accumulated oil may cling to passing ships, escaping the barrier. In addition, power, compressor, or pipe failure will render this system useless.

Chemical Barriers. (pp. 25-26) Chemical barriers are formed with fatty acids which have a high spreading force applied at the periphery of a spill; these fatty acids repel the petroleum oil, displacing it elsewhere, or pushing it into a thickened oil lense 0.5 to 1.0 cm thick. Chemical barriers are probably most efficient only to reduce the initial spread of oil and not for long-term containment.

Removal (pp. 26-36, D-18 to D-33)

Removal of oil spills is by one of the following methods:

a. Mechanical-operating purely by physical means such as skimmers, collectors, booms and weirs.

b. Chemical-depending on chemical properties of materials such as emulsifiers, combustion promoters and biodegrading agents.

c. Chemomechanical - a combination of mechanical and chemical means for removing including sinking, sorption and agglomeration.

Mechanical Methods. (pp. 26-31) Mechanical methods currently include skimming with a suction device or weir, and rotating drums or endless belt pickup.

In general, suction devices are only effective on relatively thick slicks; in addition a large amount of water is usually picked up with the oil so an oil/water separation device is needed. If the oil and water pass through a pump impellor during pickup, a water-in-oil emulsion may be formed that is very stable and difficult to break up.

Most skimmers in use at Naval facilities are converted LCM's with an adjustable lip or weir at the forward end. These are generally sensitive to environmental factors, particulary waves. One disadvantage of the self-contained unit is that routine maintenance of breakdowns will remove the unit from service.

Oil can be removed from the surface by a rotating drum or endless belt of an oleophilic material. After pickup, the oil is scraped or squeezed off. These are generally ineffective in wave heights greater than 6 inches because the water/oil surface is disturbed before the oil has a chance to contact the oleophilic material. Although the rate of pickup is slow, the oil to water ratio is better than 90 to 1 when surface conditions are not rough. The above mentioned oil slick recovery techniques may require auxiliary equipment such as oil-water separators or oil retention equipment.

If straw or other absorbant material is used, mechanical spreaders may be used to distribute the sorbant on the slick. This material must then be harvested, and this is usually accomplished by manual labor using pitch forks and rakes

Sinkants such as carbonized sand may also be used in conjunction with mechanical spreaders but oil removed in this way is generally not permanent.

Chemical Treatment. (pp. 31-34, F-1 to F-3) Chemical treatment includes dispersion with emulsifiers, burning, or biodegradation.

Emulsifiers disperse the oil into a stable oil-in-water emulsion which will eventually degrade naturally. Degradation may be enhanced by the increased surface area, or retarded due to toxic constituents. Also oil may recoalesce on the surface without continued agitation or tidal flushing. The amount of oil emulsified with a given amount of dispersant varies with the oil type, method of application, slick thickness, temperature and environmental factors, but in general is about 1 part dispersant to 5 parts oil. Emulsifiers have a high biochemical oxygen demand as well as being toxic to many marine organisms.

In most cases oil will not burn without assistance from a combustion promoter. Combustion promoters may contain substances to ignite, maintain, and/or assist combustion. Burning is influenced by the environment as well as the composition of the oil and any water emulsified in the oil. Organisms which degrade oil are present naturally in the environment and are one of the major mechanisms for the natural disappearance of oil. The rate at which microorganisms oxidize hydrocarbons is influenced by the dispersion, and solubility of the hydrocarbon, and the water temperature, but is generally too slow for practical oil removal.

<u>Chemomechanical Treatment</u>. (pp 34-36, F-1) Carbonized sand and other sinking agents have been used to sink oil but this method is not recommended unless the prevention of an immediate fire hazard is required and more satisfactory means are not available. FWQA recommendations on the use of sinking agents are contained in Appendix F of CR 71.001.

Sorbents, primarily wheat straw, are in general use for cleanup of harbor spills. Straw, which is most effective on Navy Special and Distillate fuels, is generally available at low cost, but requires considerable manpower to recover it. Polyurethane and other high molecular weight polymers have also been used successfully for oil cleanup.

Gelling agents sprayed on the oil to congeal it are still relatively expensive; in addition, satisfactory mechanical devices to recover the congealed oil are not available.

Disposal of Recovered Material (p. 36)

Most recovered oil mixtures can be consumed as fuel in industrial or ship power plants that have special provisions for this source of fuel. Most Naval shipyards and some other facilities have limited disposal facilities. However, where such disposal is not available, disposal must be at inland sites. Such sites must be carefully selected to insure that contamination of groundwater does not occur. Disposal may be accomplished by burning but the smoke generated is very objectionable unless high temperatur furnaces are used.

EFFECTIVENESS (pp. 37-53)

Effectiveness parameters include fuel oil types, and spill location, frequency, and size. Criteria for evaluation of systems under these parameters based on presently available equipment and materials include: completeness of oil removal, rate of removal, hazard and pollution, use in limited access areas, sensitivity to expected environmental factors and temperature extremes, toxicity to marine life, and system availability.

Parameters

Size of Spill. (p. 37) For purposes of this study, three sizes of spills were used: 2700 gallons (10 tons), 270,000 gallons (1000 tons), and 6,750,000 gallons (25,000 tons).

Location of Spill. (p. 37) The time available for spill cleanup is a direct function of spill location and local hydrographic and meteorologic environment. Two locations were chosen: 3 miles and 12 miles from shore. Mid-ocean spills were not considered because spreading and disposal is so rapid, cleanup equipment could not arrive quickly enough to be effective.

Frequency of Spills. (p. 38) The spill frequencies of one casualty per vessel per year were based on casualty records for 1966 and 1967 for U.S. registered vessels world-wide and foreign vessels in U.S. waters. Thus, ten 270,000-gallon spills, and one 6,750,000-gallon spill might be expected per year. The number of 27,000-gallon spills was not estimated due to lack of data, but the frequency was varied to determine the effect.

Petroleum Products Spilled. (pp. 7-9, 39) The petroleum products considered were JP-5, Navy distillate, Navy Special and Bunker C.

Characteristics of Oil. (pp. 9-15, 41-44) The fuels range from a low density, low viscosity material to a high density, high viscosity material. Initial spreading occurs rapidly until the slick thickness reduces to about 2 cm (about 1 min for a 26,400-gal spill). Later spreading depends on physical properties of the oil; for example, Bunker C would not be expected to spread to less than 2 cm thickness. After 24 hours, however, the other oils considered would have thinned to between 0.0008 and 0.0012 in. The material requiring most rapid treatment, on the basis of spreading rates, is JP-5, followed by Navy Distillate, Navy Special and Bunker C. Viscosity has only a minor influence on the rate of spreading, particularly during the initial stages of spreading.

In addition to movement by spreading, an oil slick will also move with a water current at about the same velocity, and will move due to wind at 3 to 4% of the velocity of wind. With the higher density oils such as Bunker C, another consideration is the tendency to form a water-in-oil emulsion, or "chocolate mousse"; this forms when there is agitation of the oil and water. The natural processes, such as oxidation and biodegradation, have little effect on this very stable emulsion.

Property Damage. (pp. 18-19) JP-5 causes little property damage and can generally be washed off with water. The heavier oils, particularly Bunker C, are difficult to remove being relatively resistant to detergents and solvents. All 4 fuels are harmful to natural rubber and some plastics.

Hazards. (pp. 15, 44) Prevention of spreading by containment with booms, particularly JP-5, may cause a fire hazard; this may be minimized by applying dispersants; without containment, danger of fire would exist only with JP-5, of the 4 fuels considered, and then for only 5 to 10 minutes following the spill. If material, such as wood, was available to act as a wick, fire could occur, but would be concentrated at the wick.

Certain types of sorbents may create visibility or ingestion hazards to personnel from dusty conditions. Sunken materials may reappear at a later time.

Sensitivity to Natural Phenomena or Floating Debris.(pp. 46-47) Suction pumps, wires and close tolerance impellors may be adversely affected by debris, although screens, strainers and baffles can be used to reduce this problem. Rotating drums and endless belts of sorptive materials are also vulnerable to damage and stalling from debris.

Based on world-wide weather data, the significant wave height for 90% probability varies from 1 to 13 feet. For this study the significant wave height during spill countermeasure operations was taken as the average, 5 feet, and the significant wind speed as 20 mph.

Toxicity to Marine Life. (pp. 15-18, 47) The biological effects depend on the oil, but generally, JP-5 is more toxic than diesel which is more toxic than Bunker C. In addition, the constituents of many dispersants are toxic. The actual toxic effect of a specific dispersant depends on the marine life present, the diffusion characteristics at the spill locale, the effectiveness of tidal flushing, the application rate, and the physical characteristics of the spill material. The FWQA recommendations for use of dispersants are given in Appendix F of CR71.001.

Availability. (p. 48) Reliability, maintainability and portability all influence the availability of the systems.

Results of Effectiveness Evaluation

The top 6 systems based on effectiveness are:

1. Chemical dispersants applied directly to the spill
2. Chemical dispersants plus containment
3. Advancing gravity skimmer or weir
4. Gellants/conveyor (self propelled)
5. Gellants/conveyor plus containment
6. Chemical burning agents applied directly to the spill

Containment generally does not improve the effectiveness of these systems because presently available booms are not reliable or effective for open water use. The principal difficiency of most mechanical systems is inability to function effectively in 5-foot waves and 20-mph winds. When choosing a system, local controlling factors must be considered such as: state or local pollution control regulations, port or harbor authority policy, and the proximity of shell or fin fish areas or recreation beaches.

## COST ANALYSIS (pp. 53-80)

The life cycle costs of the most effective systems were determined considering personnel hourly rate, containment booms, disposal, auxiliary surface craft, and the cost of any product used. This showed that the cost per gallon to treat oil varies with the spill size and frequency.

## COST/EFFECTIVENESS (pp. 81-87)

1. Chemical dispersants applied directly to the slick when the spill is one mile or more from shore. This appears to be the optimum choice for a universal system at present.

2. Chemical burning agents applied to Bunker C, prior to emulsification, or Navy Special while the slick is thick enough to burn. This is restricted to areas away from ships and other valuable property, and where the smoke would not be a serious problem.

3. Advancing skimmers or weirs, which have a collection rate of 1000 gal/day, are adequate for small or intermediate spills but the recovery rate is too slow for large spills.

RECOMMENDED EQUIPMENT, AND MATERIAL (pp. 87-91)

ESSM Pools (pp. 89-90)

It is recommended that the following allowance of equipment and materials be maintained on hand in the ESSM Pools and bases located at Bayonne, N. J., Guantanamo Bay, Cuba, Oakland, Calif., Pearl Harbor, Hawaii, Subic Bay, Philippines and Livorno, Italy.

1. On hand or with 4 hours notice, 20,000 gallons chemical dispersant.
2. Four 250 gpm and two 125 gpm spray booms with engines, pumps, nozzles and hardware for use on 4 large craft, 2 small craft and 8 intermediate mixer craft.
3. Two eductors for ARS fire hoses to use in applying diluted dispersants.
4. Two 3000-foot booms designed for open sea conditions.
5. On hand within 4 hours notice, 2,000 lbs of silicon dioxide powder burning agent or 20 tons of cellated glass bead burning agent.
6. Four spreaders for burning agents compatible with the type of burning agent available.

ARS Vessels (pp. 90-91)

The following equipment and materials should be located aboard ARS vessels for use against massive spills:

1. 2,000 gallons of chemical dispersant in 55-gallon drums.
2. Two 125-gpm dispersant spray booms complete with engines, pumps, nozzles and hardware for mounting on small ARS work boats.
3. Two eductors for use on ARS fire hoses to enable use of dispersants which require dilution.
4. Two 3,000-foot booms designed for open sea conditions.
5. Significant amounts of silicon dioxide powder burning agent or cellated glass bead burning agent.
6. Four spreaders for burning agents compatible with the type of burning agent to be used.

# STUDY OF EQUIPMENT AND METHODS FOR REMOVING OR DISPERSING OIL FROM OPEN WATERS

## 1. INTRODUCTION

Many types of equipment, materials, and techniques have been employed to remove spilled petroleum products from open waters. The range of credible spill situations and petroleum products with high potential involvement suggests that no single system is likely to be completely effective. This study is intended to identify and describe the most cost-effective available systems consisting of present or new combinations of existing equipment, materials, and techniques. It is also intended to identify present deficiencies and recommend specific measures for future employment by the Navy to combat spills on open waters in close proximity to valued resources. Consideration of costs, effectiveness, speed, hazards, ecological effects, environmental and geographic factors, and other constraints are included. The study focuses on the major petroleum products in current use by the Navy or planned for future use.

The technical Summary and Conclusions section outlines the findings of this study, including recommendations. The Discussion section presents technical background on the petroleum products studied (Bunker C, Navy Special, JP-5 and a new Distillate Fuel) and their behavior and fate after spillage; characteristics of reference environments and a discussion of pollution regulations; review of available equipment and techniques for cleaning; evaluation of the effectiveness of candidate systems; cost analysis of most effective systems; determination of most promising equipment, materials and techniques; development of a deployment plan; and recommendations for future research.

## 2. TECHNICAL SUMMARY AND CONCLUSIONS
## CHARACTERISTICS OF OIL AND ITS BEHAVIOR AFTER SPILLAGE

The materials in current use or planned for future use by the U. S. Navy are: JP-5 Turbine Fuel, Distillate Fuel, Navy Special Fuel Oil, and Bunker C Fuel Oil.

Physical chracteristics of these materials range from a low density, low viscosity material (JP-5) to a high density, high viscosity material (Bunker C). The Distillate Fuel, a new product which the Navy plans to employ in the next few years, physically resembles JP-5.

The behavior of these materials is described in the sections entitled Characteristics of Spill Materials and Behavior of Spilled Petroleum Products. In summary, evaporation rates after spillage would be very low for the residual materials (Bunker C and Navy Special) but would be quite significant for the lighter and more volatile materials. Evaporation rates under field conditions are highly dependent on air contact area, air velocity, and temperature. Up to 80% of spilled gasoline has been observed to evaporate in three hours under moderate wind conditions. The evaporation of the volatile products (JP-5 and Distillate Fuel) would be expected to approach such rates. For the other materials, evaporation would be minimal.

Rates of movement with surface winds would be expected to be about three percent of the wind velocity. Slicks would be expected to move at the same rates as prevailing surface currents.

Water-in-oil emulsions are unlikely to be produced with either JP-5 or Distillate Fuel. Bunker C, depending on the source crude oil, may form this "chocolate mousse" in a few hours, making its treatment more difficult. The same may be true of Navy Special, though to a lesser extent.

Unrecovered oil will ultimately evaporate, be deposited on shore, dispersed in the water or be degraded by biological organisms or photo-oxidation. Persistent materials undergo biological degradation at rates which depend on the microorganisms present, the availability of oxygen, temperature, and the degree of dispersion. These conditions vary so widely and quantitative relationships are so obscure that no meaningful rates of oxidation can be estimated.

## EFFECTS OF SPILLED PETROLEUM PRODUCTS

The effects of spilled petroleum products are described and evaluated in the section titled Effects of Spilled Petroleum Products. The following paragraphs summarize these findings.

Following a petroleum spill on waters, the risk of fire is minimal. Even when ignition has been purposely attempted, the loss of heat to the supporting water surface inhibits burning. Except for the first five or ten minutes following a spill of JP-5, there would be virtually no danger of fire from the four materials considered in this study.

Experience has shown considerable variance in oil spillage effects on marine life. Massive spills of refined petroleum products have been shown to cause extensive mortality of marine organisms. Spills of lesser magnitude can cause flavor tainting and condemnation of shellfish. Heavy oil slicks cause gross mortality of sea birds. The most harmful material to marine life considered in this study is JP-5, followed by Distillate Fuel, Navy Special and Bunker C in that order. The use of chemical dispersants or sinking agents for treatment can increase this toxicity.

The effects of oil on property are inverse to the effects on marine life. JP-5 and Distillate Fuel evaporate rapidly, are most readily dispersed, and are easily removed from surfaces. Damage by the heavier materials (Navy Special and Bunker C) is almost entirely esthetic. They are very difficult to remove from beaches, water craft, and structures, and represent the greater liability potential.

## REFERENCE ENVIRONMENTS AND GEOGRAPHY

The environmental extremes to which U. S. Navy AOs and AOGs are subjected vary widely. The near shore spill incident has much more serious implications than a mid-ocean spill due to the potential for damage to marine life and shore resources. For this reason and because of the greater probable incidence of near-shore spills, environmental factors pertaining to such spills are represented in the parameters used for evaluating cost-effectiveness of systems.

Two significant factors which affect the migration of spilled oil are the local wind and the direction and magnitude of surface sea currents. As a so-called worst case, a 90% probability case is chosen for effectiveness analysis: on-shore winds of 20 mph and 5-foot waves.

Included with geographic distinctions of environment are the regulatory constraints upon oil spillage and its subsequent treatment. Public law 91-224 titled "The Water Quality Improvement Act of 1970" was recently passed by Congress. It authorizes an expedient Federal Government effort to clean up any oil spillage which may occur in navigable water or the contiguous zone of the United States. A $35,000,000 revolving fund is set up to fund spillage control actions. Liabilities to owners of offshore facilities and vessels are limited to the following: $8,000,000 for an offshore facility and $100 per gross ton or $14,000,000 per vessel, whichever is the least. Liability must be accepted in all cases with the exception of acts of God, an act of war, or third party negligence on the part of the U. S. Government.

The Intergovernmental Maritime Consultative Organization (IMCO) has adopted conventions to allow intervention by coastal states for oil spills threatening their shorelines and imposing liabilities up to $14 million on owners and operators. These conventions must be ratified by several member nations in order to become binding internationally.

## CASE HISTORIES OF REPRESENTATIVE SPILLS

Several catastrophic spills of the order of several thousand tons of oil are described in Appendix B. Details of the spills along with attempted treatment methods, their permanence, additional damage, and shortcomings and limitations are included. Beginning with the ANNE MILDRED BRØVIG spill on February 20, 1966, the review includes the TORREY CANYON spill, the OCEAN EAGLE grounding, the GENERAL COLOCOTRONIS, the Santa Barbara Channel incident and the ESSO ESSEN spill. These spill experiences are used to assist in determining future research and in consideration of present mechanical, chemomechanical and chemical means for oil spillage control.

## OIL SPILL TREATMENTS AND RECOVERY EQUIPMENT AND TECHNIQUES

The treatment of oil spillage released to the open sea can be accomplished by the use of systems employing one or more of the following components:

- Mechanical treatment: skimmers, pumps, spreaders, collectors, booms and weirs.
- Chemical treatment: dispersants, combustion promoters and biological degradation agents.
- Chemomechanical treatment: sinking, sorption and gelling agents—all, with the exception of sinking agents, accompanied by mechanical removal equipment.

Three distinct operational areas are identified as: containment, physical/chemical elimination of the slick, and disposal of recovered products. Within these areas the spectrum of equipment and materials in present use is described. Advanced concept approaches which are in development stages are also introduced. The advantages, limitations, and shortcomings of each component or system are identified through experience and analysis.

## EFFECTIVENESS ANALYSIS

The section entitled "Effectiveness Analysis" describes the procedures involved in analyzing system effectiveness for removal of spilled petroleum products from the open sea environment. The analysis consisted of the following steps:

- Definition of effectiveness parameters.
- Definition of criteria and development of appropriate indices.
- Computation of the relative effectiveness of candidate systems under all combinations of parameters.

Parameters are defined as the characteristics of reference spill environments and spill frequencies deduced from casualty data. They were:

| | |
|---|---|
| Spill Size and Frequency | -10, 50 and 100 @ 2,700 gallons, 10 @ 270,000 gallons 1 @ 6,750,000 gallons |
| Spill Material | JP-5, Distillate Fuel, Navy Special, and Bunker C |
| Location | -3 and 12 miles from valued shore areas. |

Effectiveness criteria were taken as: (a) completeness of removal of spilled material: (b) speed of removal; (c) effect of pollution or hazard; (d) applicability to limited access areas; (e) sensitivity to environmental factors; (f) sensitivity to temperature; (g) toxicity to marine life; and (h) availability.

Equipment, materials, and techniques potentially capable of meeting the criteria within the defined parametric ranges were classified as follows:

- Chemical
- Chemomechanical
- Mechanical

They are described under the section on Oil Spill Treatments and Recovery Equipment and Techniques.

Each system within these classifications was considered with and without containment. The addition of this capability does not, however, improve the effectiveness of every system. Both hypothetical and existing systems of oil recovery are considered in the effectiveness analysis. Hypothetical systems were composed of the possible combinations of individual equipment pieces, materials, and techniques comprising existing systems. A total of 21 systems were considered as being potentially effective. Of these, 13 were superior and of these, one (biological degradation agents) is judged impractical because of inability to meet requirements for rate of removal by several orders of magnitude. The potential systems in descending order of effectiveness are shown in Table 1 following:

Table 1
Effectiveness Ranking of Candidate System

| | System | Effectiveness Index Total Score |
|---|---|---|
| 1. | Chemical dispersants applied directly to the slick | 229 |
| 2. | Chemical dispersants plus containment | 151 |
| 3. | Advancing gravity skimmer or weir | 133 |
| 4. | Gellants/conveyor (self-propelled) | 132 |
| 5. | Gellants/conveyor plus containment | 124 |

Table 1 (continued)
Effectiveness Ranking of Candidate System

| | System | Effectiveness Index Total Score |
|---|---|---|
| 6. | Chemical burning agents applied directly to the slick | 120 |
| 7. | Enhanced degradation (addition of bacteria, enzymes, etc.) | 120 |
| 8. | Chemical burning agents plus containment | 114 |
| 9. | Advancing gravity skimmer or weir plus containment | 109 |
| 10. | Sorbents/conveyor (self-propelled) | 107 |
| 11. | Endless belt on water surface | 106 |
| 12. | Sorbents/suction device plus containment | 93 |
| 13. | Sorbent/conveyor plus containment | 91 |

## COST ANALYSIS

Cost estimates were derived for the twelve systems deemed superior by the effectiveness analysis. Fixed as well as variable costs are computed for each spill size and frequency: 10, 50 and 100 spills of 2,700 gallons, 10 spills of 270,000 gallons and one spill of 6,750,000 gallons. Cost per gallon of spilled material treated was computed for each case. It was found that costs per gallon are spill size dependent and for small spills, frequency dependent.

## IDENTIFICATION OF MOST COST EFFECTIVE SYSTEMS

Cost data and effectiveness index scores were combined by dividing the cost per gallon of oil treated by the system effectiveness index. The system having the lowest cost-effectiveness ratio is the most favorable.

Based upon the cost effectiveness analysis, the most cost-effective systems for treating oil spilled on open sea waters are:

(1) Chemical burning agents applied to Bunker C before emulsification or to Navy Special when the slick is thick enough for burning. This method is restricted to areas away from valued property and where air pollution would not be considered a problem. JP-5 and Distillate Fuel would likely spread too thin for burning.

(2) Chemical dispersants applied directly to the slick, where the spill is one mile or more from shore. This system is the most logical choice for a universally applicable system.

(3) Advancing skimmers and weirs for small and intermediate spills. Large spills are beyond present skimmer capability.

## RECOMMENDATIONS

### Systems

Considering the cost-effectiveness analysis results, limitations of these systems and present research efforts, it is recommended that for disaster type spills, the following systems be used:

(1) Chemical dispersants applied directly to a slick.
(2) Chemical dispersants plus containment devices.
(3) Burning.

Advancing skimmer development efforts are underway which may be expected to eventually produce a workable system for large spills. Open sea boom development is also being undertaken which can be expected to result in improved boom designs for oil spill containment in the future.

### Deployment

The following equipment and materials are recommended to be stored or be available on short notice at selected sites and be located aboard ARS vessels for combatting massive open sea oil spills:

(1) 20,000 gallons of chemical dispersant.
(2) Six spray booms complete with ancillary equipment. Four large surface craft must be on four-hour readiness call.
(3) Two eductors for use on ARS fire hoses.
(4) Two 3,000-foot open sea booms.
(5) 2,000 lb of silicon dioxide or 20 tons of cellated glass bead burning agents.
(6) Four spreaders for application of burning agents.

The strategic sites recommended for storage of the above are listed below:

(1) ESSM pool at Bayonne, New Jersey, USA
(2) ESSM pool at Guantanamo Bay, Cuba
(3) ESSM pool at Oakland, California, USA
(4) ESSM pool at Pearl Harbor, Hawaii, USA
(5) ESSM pool at Subic Bay, Philippines
(6) 8th Army Logistics Command Base at Leghorn, Italy.

### Future Research and Development

The evaluation of the systems considered in this study brought out shortcomings in several of the proposed methods and equipment for treating oil spills. Recommended future research is classified as: (1) improvements to equipment and methods, (2) innovations, (3) spill technology, and (4) spill management. Particular recommendations identified under each of these items are given below:

Improvements to equipment and methods - (a) develop or identify an open sea compatible boom, (b) institute a testing program for mechanical methods, and (c) develop large capacity skimmer concepts.

Innovations - (a) develop sorbent or gellant harvesting devices, and (b) investigate the use of emulsified fuel oils for Navy ship fuel.

Spill Technology - (a) develop an accurate method of measuring or estimating slick thickness and volume, (b) determine the tendency of Navy Special to form stable water-in-oil emulsions, (c) determine the most cost-effective dispersants for use in treating spilled products from U. S. Navy vessels, and (d) determine the most cost effective burning agent for specific oils used in U. S. Navy vessels.

Spill Management - (a) determine and record available locations for use as disposal sites for recovered oil, (b) provide formal training for Naval anti-pollution control teams, (c) inventory available anti-pollution equipment, materials and personnel at major U. S. Navy port and harbor locations, and (d) develop a detailed response plan for nominal or massive spills of U. S. Navy oil products.

Details of the above recommendations are given in their appropriate locations in the sections entitled: E. Cost Analysis, F. Deployment Plan, and G. Recommendations for Future Research.

## 3. DISCUSSION

### A. CHARACTERISTICS OF SPILL MATERIALS

Four fuel oils have been considered in this study: Bunker C Fuel Oil, Navy Special Fuel Oil, Distillate Fuel, and JP-5 Turbine Fuel. The published properties of these fuels are listed in Table 2.

Bunker C Fuel Oil is the principal industrial boiler fuel oil. It is also known as No. 6 fuel oil and PS400 fuel oil, is a commercial product, and there is no military specification for it. It is a residual oil, i.e., it is what is left after the more volatile components have been distilled out of the crude oil. Some of the original contaminants, such as sulfur, remain in the residual oil. Its characteristics can vary rather widely and depend upon the properties of the crude oil from which it is extracted. It is a very viscous, tarry oil which is sometimes heated to reduce viscosity before pumping. It is a heavy oil, and, in some cases, may have a specific gravity as large as 1.07 at 60 °F. A representative value for the specific gravity of sea water at 60 °F is 1.025.

The characteristics of Navy Special Fuel Oil are given in Military Specification MIL-F-859E, Amendment 2, 4 August 1967, "Fuel Oil, Burner." It consists of a hydrocarbon (petroleum) oil with no additives.

The characteristics of the Distillate Fuel are given in Military Specification MIL-F-24376 (SHIPS), 27 January 1969, "Fuel, Reference, and Standard Distillate." It is a petroleum distillate with chemical additives which may include any or all of the following:

| | |
|---|---|
| Antioxidant | 9.1 g/100 gal fuel (U.S.) Maximum |
| Metal deactivator | 2.2 g/100 gal fuel (U.S.) Maximum |

The characteristics of JP-5 are given in Military specification MIL-T-5624G, Amendment-1, 21 November 1966, "Turbine Fuel, Aviation, Grades JP-4 and JP-5". This fuel is a high flash-point kerosene required by the U. S. Navy primarily for carrier operations. Very few, if any, commercial turbine fuels satisfy the JP-5 specifications. JP-5

Table 2. Petroleum Product Properties

| | Bunker C Fuel Oil | Navy Special Fuel Oil | Distillate Fuel | JP-5 Turbine Fuel |
|---|---|---|---|---|
| Gravity, °API | 1-10.8 | 11.5 min. | 27 min. | 36–48 |
| Specific Gravity 60/60 | 1.067–0.994 | 0.989 max. | 0.893 max. | 0.845–0.788 |
| Flash Pt., min., °F | -- | 150 | 150 | 140 |
| Viscosity | | | | |
| SUS @ 85°F | -- | 225 min. | -- | -- |
| SUS @ 122 °F | -- | 225 max. | -- | -- |
| SSF @ 122°F | 125–200 | -- | -- | -- |
| Kinematic, | | | | |
| cS @ 100°F | -- | -- | 2.0–10.0 | -- |
| cS @ -30°F | -- | -- | -- | 16.5 max. |
| Fire Point, °F min. | -- | 200 | -- | -- |
| Flash Point, °F min. | -- | 150 | -- | -- |
| Freeze Point, °F min. | -- | -- | -- | -51 |
| Explosiveness, % max. | -- | 50 | 50 | 50 |
| Pour Point, °F | 30–60 | 15 | 20–30 | -- |
| Aromatics, vol% max. | -- | -- | -- | 25 |

comprises the basic petroleum base (high flash-point kerosene) and a group of chemical additives which may include any or all of the following:

| | |
|---|---|
| Antioxidant | 9.1 g/100 gal fuel (U.S.) Maximum |
| Metal deactivator | 2.2 g/100 gal fuel (U.S.) Maximum |
| Corrosion inhibitor | 18.2 g/100 gal fuel (U.S.) |

Representative variations and ranges of viscosity and specific gravity with temperature for the four petroleum products considered are shown in Figures 1 and 2. The ranges of viscosity and specific gravity have been estimated from data obtained from suppliers and in literature of suppliers of some of the different products.

## BEHAVIOR OF SPILLED PETROLEUM PRODUCTS

The edge of an oil slick can move in two ways--the slick can spread out and cover more area, and it can move as a unit under the influence of current or wind. The movement of the edge of the slick would equal the algebraic sum of the two components.

### Spreading

Very little information is available in the literature on the spreading of large quantities of oil. The dearth of information is due, at least in part, to the strong public objections to the pollution which would result from performing large-scale experiments with petroleum on bodies of water. Some small-scale experiments have been conducted, however, and their results have contributed to a knowledge of the mechanics of spreading.

Observations have been made of the spreading which followed large, accidental spills and from these some general relationships have been deduced. Kluss[1] estimated as a quick rule of thumb for operational use 1000 tons (approximately 270,000 gallons) of crude oil might be expected to form a film of oil on the surface of the sea about one millimeter thick and 1000 tons of that thickness would cover about one-third of a square mile. For heavy crudes in cold weather, the thickness might increase to five millimeters and the area covered would then be less then one-tenth of a square mile. The time required for the 1000 tons to spread out to one millimeter thickness would be about six hours.

Berridge,[2] et al. investigated the rate of spread of a homogeneous oil slick for a group of crude oils with specific gravities ranging from 0.829 to 0.896. Their work indicated that the thickness of the slick tended to keep reducing, and the area increasing, until the thickness of the slick, for the oils tested, reduced to 0.0008 to 0.0012 in. The time required for a spill of 100 $m^3$ (26,400 gal) of oil to reduce to a slick of that range of thickness was 27.7 hours. They also observed that, for their samples, the slicks became distorted and moved bodily at speeds greater than the rate of spreading when the wind velocity reached 3 mph (4.4 ft/sec). In addition, they verified many of the findings of Blokker[3] and modified the equation (that he developed) relating slick radius and time to give a relationship for slick thickness vs. time--

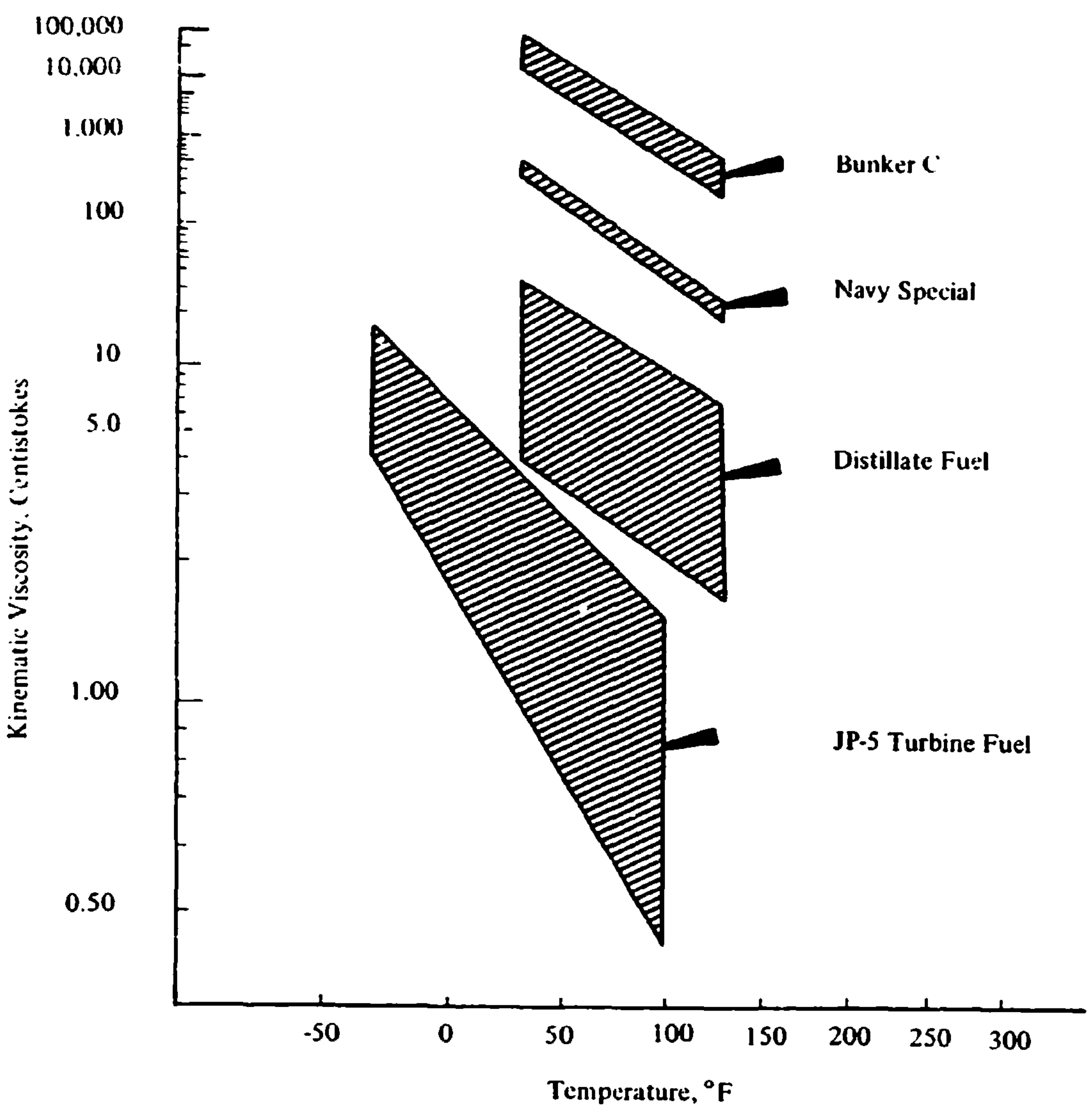


**Figure 1 Range of Viscosity Versus Temperature For Bunker C, Navy Special, Distillate Fuel, and JP-5 Turbine Fuel**

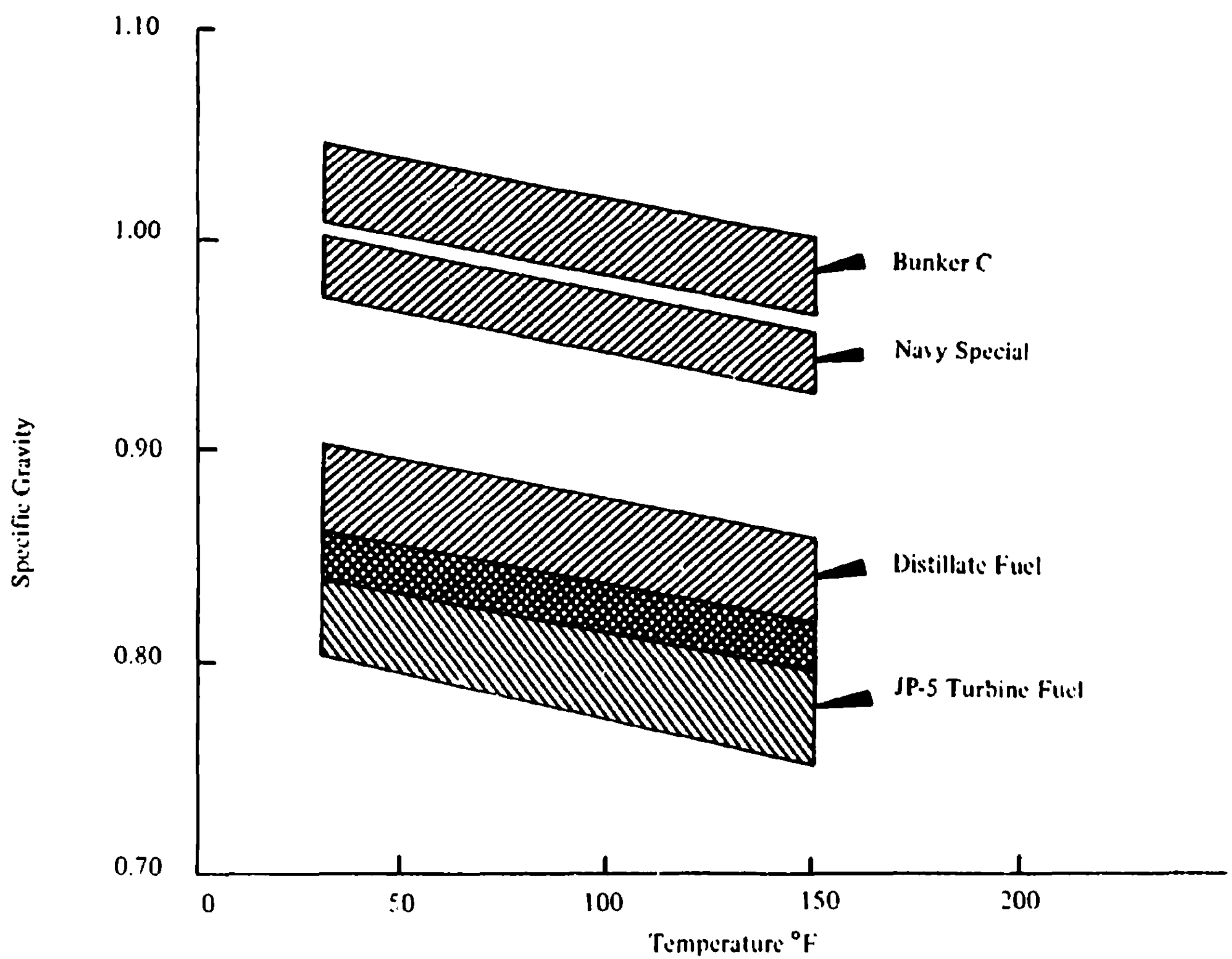


**Figure 2 Range of Specific Gravities Versus Temperature For Bunker C, Navy Special, Distillate Fuel, and JP-5 Turbine Fuel**

slick thickness $= K\,t^{-2/3}$ where t = sec, slick thickness = cm,

$$\text{and } K = (v\,\pi)^{1/3} \left[\frac{\rho_W}{3\rho_0\,(\rho_W - \rho_0)\,K_1}\right]^{2/3}$$

where $v$ - volume of oil, cm$^3$

$\rho_0$ - density of oil, g/cm$^3$

$\rho_W$ = density of water, g/cm$^3$

$K_1$ - a constant for a given oil

This relationship shows that the tendency for the oil slick to expand is, in part, a function of the difference in the densities of the oil and the water. As the difference approaches zero (as for a Bunker C Fuel Oil) the spreading force also approaches zero.

Blokker also determined that the rate of spread of a homogeneous oil slick is approximately proportional to the instantaneous mean layer thickness. The spreading rate is also influenced by the viscosity surface tension, interfacial tension between water and oil, density, chemical composition, pour point of the oil, current, and, as previously noted, wind speed.

The value of the pour point of an oil may have a profound influence on its spreading characteristics. An oil with a pour point higher than the temperature of the water, as could be the case with some Bunker C's, would form a semisolid mass that would have very little tendency to spread, particularly if its specific gravity approaches that of sea water.

Both Blokker and Berridge concurred in the finding that spreading velocity is not a direct function of the viscosity of the oil as might have been expected. The influence of viscosity is relatively small, especially during the initial stages of the spill Blokker, for example, noted that the time required for spilled oil to spread out to a slick of 2 cm thickness was very short, on the order of one minute for 100 m$^3$ for spills of oils with viscosities ranging from 0.8 to 490 centipoises at 20°C. Berridge, et al., found, as previously noted, that the thickness of the slicks resulting from 100 m$^3$ spills of oils with viscosities ranging from 4.13 to 25.0 centistokes at 100 °F was fairly uniform after 27.7 hours.

## Movement with Winds and Current

An oil slick, or a blob of high-density oil, will move as a unit under the influence of water current or wind velocity. The oil will move at the same velocity as the water current when conditions have stabilized, providing no other forces are acting. The relationship of oil slick velocity to wind velocity is not so simple, however, and different investigators have arrived at different conclusions.

Brockis[4] quotes the results of a series of experiments carried out in Japan, coordinated by the Maritime Safety Agency. They determined that the oil slick moved with the wind at a rate of about 4% of the wind speed. Smith[5] reports that the results of a series of careful observations of wind velocity and oil slick movement, taken at 6-hr intervals from a land meteorological station, indicated an average rate of oil slick movement equal to 3.4% of the wind speed with the movement in essentially the same direction as the wind. He

also quoted results obtained by Hughes[6] who found that plastic envelopes floating close to the surface of the Atlantic Ocean moved parallel to the direction of surface wind at 3.3% of the wind speed. The German Hydrographic Institute reported using a drift of 4.2% of the wind velocity to predict movement of an oil slick from the ANNE MILDRED BROVIG.[7] Theoretical calculations employing drag forces indicate slick movement of about 3.0% of the wind speed.[8]

One other factor that affects the direction of travel of an oil slick is the component due to the Coriolis acceleration. If the wind has a north or south directional component, the oil slick will not move in the exact same direction as the wind but will veer off at a slight angle due to its change in latitude. In the northern hemisphere any southerly wind-induced movement will be accompanied by a slight westerly component of the oil-slick velocity. A northerly component in the wind velocity will produce an easterly drift. In the southern hemisphere the drift components of the velocity will be reversed, i.e., south wind-eastward drift and north wind-westward drift.

Based on the results of the different investigators reviewed above, it would appear that the speed of movement of an oil slick as a unit, due to the drag force exerted by a wind blowing across its surface, would be in the range between 3 and 4% of the wind speed.

Water-in-Oil Emulsions

Another factor which can greatly affect the rate of spreading of an oil slick as well as its thickness is the tendency of the oil to form a water-in-oil emulsion with the sea water.

The effect of the water-in-oil emulsion caused by wave action on the open sea was noted in the review of the Torrey Canyon disaster. The emulsion was named and referred to as "chocolate mousse". The exact color and consistency of the emulsion varied with the amount of water dispersed in the crude oil and the degree of oil weathering. In general, the "chocolate mousse" had a consistency of a thick salad cream. The water content ranged from 50 to 80%, and the size of the water droplets varied in different "mousses".

Water-in-oil emulsions form when there is agitation of a layer of oil in the sea provided that the oil contains a natural occurring surface active agent which promotes this formation. The jelly-like resulting emulsion greatly reduces the spreading of the oil. It also inhibits the action of dispersing agents.

Such emulsions studied and reported on have been primarily those formed with crude oil, notably the ones formed during the Torrey Canyon disaster. R. A. Dean[9] reported that the Torrey Canyon disaster demonstrated clearly that the formation of water-in-oil emulsions occurs quite rapidly at sea with some types of crude oil. The "chocolate mousse" emulsion is remarkable in that it is more like a gel than an oil.

The formation of water-in-oil emulsions leads to stable "naps" of oil which are dispersed by natural agencies only very slowly and can travel long distances. This phenomenon considerably increases the extent of the coastline menaced by a spill and the persistence of the menace. In principle, all the methods of removing homogeneous oil slicks are applicable to the removal of water-in-oil emulsions, although the amount of pollution needing to be collected is increased (by 500 percent in the case of "chocolate mousse").[2]

The natural phenomena such as oxidation, bacteria, etc., believed to have some affect on the rate of removal of a thin film of oil spread on the open sea, were found to have no significant affect on the removal of lumps of "mousse" during a three-month period of

experiments where mousses were exposed to conditions simulating rich pools of aerated seawater.[10] The "mousses" remained very stable and showed little sign of breakdown, except for the loss of distillate fractions from some of the lighter crudes tested.

Berridge[10] concluded that asphaltenes, or similar materials, are, in all probability, the main "mousse" forming agent. The asphaltenes are further described as the non-volatile asphaltic residual components from crude oil. Canevari[11] identified the natural emulsifier in crude oil as a porphyrin compound. The behavior of Kuwait crude after extraction of the emulsifier was completely different with regard to spreading and forming stable water-in oil emulsions.[11] In the laboratory, "mousse" is effectively broken into oil and water layers by nominal addition of surface-active agents (e.g., 0.1 to 1.0% of BP-1002) and vigorous agitation.[10]

"Mousse" forms readily in the laboratory when thick layers of crude oil are agitated on the surface of seawater, and when agitated with seawater using a paddle mixer or bubbling air.[10]

Tests by Berridge, et al., failed to produce "mousse" emulsions with gasoline, kerosene, auto diesel, marine diesel, lube oil 600, paraffinic lube oil 2500, or heavy napthenic lube oil 1500 using the same techniques which readily made "mousse" from a variety of crudes and from Bunker C.

Based on this evidence and the rapid spreading of distillates, it is unlikely that a "mousse" would form with spilled JP-5 Turbine Fuel or Distillate Fuel. However, it will form with Bunker C, provided that the source crude contains a natural emulsifier. The resulting "mousse" is stable. Conditions believed to simulate rough seas resulted in "mousse" formation in less than an hour[10]. It is possible that Navy Special Fuel Oil would form a "mousse" emulsion.

The tendency for the Navy Special Fuel Oil to form a water-in-oil emulsion when agitated on the surface of seawater should be checked. The stability of the resulting emulsion, if any, should also be checked. The properties of a refined oil such as the Navy Special Fuel Oil may be very different from those of a crude oil.

## Fate of Unrecovered Material

Oil which is not recovered from the water may remain either dissolved in the water (a small amount), on the surface or suspended in the water, adhering to structures or rocks, mixed with the sand at the shoreline, or on the bottom of the sea if it has been sunk with a sinking agent. The small amount that is in solution will largely be dissipated rapidly by current and tides, though residuals may persist for many weeks in a closed area such as a bay or harbor. Oil which has been mechanically sunk to the bottom will largely break loose, little by little, and rise slowly to the surface. This oil, the oil remaining in the water, and that adhering to structures or shore, will be gradually degraded biologically.

Report of an extensive study by ZoBell[12] concluded that, "Virtually all kinds of oils are susceptible to microbial oxidation. The rate of such oxidation is influenced by the kinds and abundance of micro-organisms present, the availability of oxygen, temperature, and the dispersion of the oil in water. Microbial oxidation is most rapid when the hydrocarbon molecule is in intimate contact with water and at temperatures ranging from 15 to 35 °C;

some oxidation occurs at temperatures as low as 0 °C. An average of one-third of the hydrocarbon may be converted into bacterial cells, which provide food for many animals. The remaining two-thirds of the hydrocarbon is oxidized largely to $CO_2$ and $H_2O$. In the marine environment, oil persists only when protected from bacterial action".

Based upon rates at which marine bacteria have been observed to oxidize various kinds of mineral oils under controlled laboratory conditions and upon information on the abundance of bacteria in the sea, it is estimated that oil might be oxidized in the sea at rates as high as 100 to 960 $mg/m^3$ day or 36 to 350 $g/m^3$ year.

In summary, if environmental conditions (nutrients, temperature, and oxygen availability) are satisfactory and if suitable microbial populations are present, oil will be degraded in the ocean. However, the rates of hydrocarbon degradation are slow when compared with those of the oxygenated derivatives. There has been much speculation recently about the ability of highly specific cultures to rapidly degrade oil spills, yet a dearth of specific information is evident.

## EFFECTS OF SPILLED PETROLEUM PRODUCTS

### Flammability

A risk of fire occurs primarily when the concentration of hydrocarbon vapor in the air lies within the range of flammability. A definite fire danger would exist with spilled gasoline, a light crude oil, or a wide-range aviation turbine fuel. JP-5, however, is a high-flash-point turbine fuel and would present little danger after the first five or ten minutes following the spill. The danger of fire after that time could occur from pieces of wood or other material caught in the oil slick and which could act as a wick. In such a case, however, the fire would burn only at the wick. The large amount of water would act as an effective coolant and prevent heating of the oil layer surrounding the wick to the vaporization temperature. It is reported by Blokker[3] that layers of products such as kerosene, gas oil, lubricating oil, and fuel oil on water cannot burn at all without a wick. It has also been reported by Diedericksen[13] that oil on the sea in a thickness of less than about 3 mm (0.118 in.) will not burn. The difficulty of igniting spilled oil was demonstrated in an experiment reported by Brockis[4] in which the use of a flame thrower was required to ignite Iranian crude five minutes after a spill. It should be remembered here that a crude oil contains light fractions and is definitely more flammable than any of the fuel oils being considered. Another study reported that weathered oil is difficult to ignite and poses no real fire hazard.[7]

Except for the first five or ten minutes following a spill of JP-5, there would be very little danger of fire from spills of any of the four subject oils.

### Effects of Oil on Marine Life

In recent years, a variety of different oils and oil products have been inadvertently released into the marine environment. The biological effect of the spilled substance is related to the material released. Some compounds are more toxic than others. Lapatz[14] reported the following listed in order of decreasing toxicity to fish: gasoline > diesel oil > Bunker C. To this list can be added JP-5 which is more toxic than gasoline and crude

oil which is the least toxic of all[8]. JP-5 is an avation turbine fuel. It is a lighter hydrocarbon than the others, and it spreads more rapidly. Also, JP-5 is more miscible with water and therefore represents a greater threat to marine life. It will contaminate shellfish and other seafood organisms and render them unfit for human consumption for periods up to 6 months[8]. JP-5 has been shown to be toxic to fish, crabs, and lobsters[8]. Additionally, this fuel contains chemical additions. Unfortunately, little is known about the toxicities of the JP-5 additives.

A spill near shore is potentially more dangerous than one in the open sea. Most effects of an oil spill are noted when it reaches the beach. Of all the types of organisms affected by oil, sea birds seem to be the most vulnerable. It is near shore where most of the sea birds are found. Apparently the intertidal organisms are relatively unharmed by contact with crude oil; immediate losses may be expected to reach 5-10%. Those animals lost are rapidly replaced from surrounding unaffected areas[5].

Oil in the vastness of the open sea represents less of a threat to marine life than its minimal effect on intertidal species. This is a result of relatively fewer organisms per volume of water and the fact that the organisms are not forced into contact with the oil. Midwater trawls by the R/V David Star Jordan following the Santa Barbara incident revealed no damage to pelagic fish eggs or larvae, phytoplankton, or zooplankton from acute exposure to oil[15].

Whales, porpoises, seals, and sea lions constitute a group of animals that may come into direct contact with oil slicks. Although several seals were observed to be coated with oil in the Santa Barbara Channel, none appeared to be in distress[15]. Autopsies performed on two porpoises found in the same area failed to incriminate oil contamination as the cause of death. In general, although most mammal species in the Santa Barbara area received some oil coating, minimal effects were attributed to the oil. The seals and sea lions which became covered appeared normal. The whales migrating through the channel either were able to avoid the oil or were unaffected when in contact with it.

## Effects of Oil Treatment Agents on Marine Life

After a relase of petroleum has occurred on the ocean, measures must be taken to remove it before it causes injury to life or property.

Treating agents presently available for removal can be placed into two categories: (1) Chemomechanical treatment by a method that facilitates the removal of the oil from the water, or by sinking the oil by addition of a high density substance, (2) Chemically dispersing the oil in the bulk of the sea. The first method presents no additional insult to the biota because it does not alter the chemical composition of the pollutant. It may, however, allow an increase in frequency or duration of contact between the oil and the life forms.

Sinking oil by addition of a high density agent merely removes the oil from the surface. It does not solve the problem and, in fact, it very likely creates a new one. Carbonized sand is a frequently used sinkant. When spread on an oil slick, it may remove 50-70% of the oil from the sea surface and deposit it on bottom fishing grounds, shellfish beds, or fish spawning areas[5,8]. A further disadvantage of sinkants is that with time the oil may be released and rise to the surface again[5,8].

The function of a dispersant in the second method is to dispose of the oil by formation of an oil-in-water emulsion which will eventually degrade by bacterial action. Utilization of dispersants is objectionable because they are toxic. Acute effects of some dispersants on indicator organisms (shrimp, crab, and bivalves) are detectable at concentrations of 1.0 to 10.0 ppm[16]. A dispersant must be evaluated with respect to the area and volume it will occupy as a function of time. This evaluation should be based on what changes the dispersant will cause in the physical, chemical, and biological characteristics of the environment.

The chemical composition of a number of dispersant chemicals is: surfactants (10-15%), solvents (70-80%), and stabilizers (10-15%)[8].

Functionally, the major constituent of dispersants is the surfactant which alters the surface tension of the pollutant allowing it to spread and form a colloidal suspension: the stabilizer prohibits recoalescence and the solvent aids the surfactant in penetrating and mixing with the oil. Most solvents are petroleum or water based. The toxicity of the dispersant constituents varies and can be arranged in the following order: solvent > stabilizer > surfactant. It should be pointed out that what is generally the most toxic component, the solvent, comprises 70-80% of most dispersant chemicals.

The rate of application of dispersant chemicals recommended by manufacturers varies, but generally it approximates 1 part dispersant to 10 parts oil. In practice it has been found that 2 to 3 times this amount of dispersant is required.

As was mentioned above, many of the dispersant chemicals are toxic. Acute effects in some animals may be detected at less than 1 ppm. As the concentration increases, the effects mount progressively and extend over a wide variety of species. A one-hour exposure to 10 ppm of many dispersants is lethal to most planktonic and sublittoral organisms[5].

With time, however, some of the toxicity of the emulsion is lost. Much of the solvent and stabilizer phase of the dispersant, the two most toxic fractions, is lost in the first 24 hours.

Extensive toxicity information on oil spill treating agents massively applied is limited to the incident of the TORREY CANYON disaster[5] and is further confined to dispersants. Findings from this incident should be viewed as a most extreme example–environmental conditions, sensitivity of resources exposed, treatability of the oil involved and the geographic location were all adverse. Conclusions drawn from this incident must, therefore, not be considered as typical but rather as from a scene approaching the "Worst Credible Incident."

The relatively little damage suffered by planktonic organisms in the open sea following the release of oil and its treatment with dispersants was surprising in view of the magnitude of both the oil released and the quantity of agent applied. However, after the circumstances concerning the pollution were better documented, a more informed view was formulated.

Laboratory experiments showed that toxicity attributed to dispersants is primarily due to aromatic components. These fractions are lost through evaporation in a period of two to five days[5] in the open sea. The maximum solubility of aromatic hydrocarbons, however, is of the order of 30 to 800 ppm[5], and the dissolved aromatics could therefore persist in highly toxic concentrations. However, it was believed that wind conditions prevalent, of sufficient strength to achieve vertical mixing, would also enhance evaporation of the toxic aromatics from the sea surface. The effect of spraying oil in the open sea, therefore, was to produce patches of oil and dispersant which would be driven steadily before the wind for

two or three days. During this time the major fraction of aromatic components would be diluted and lost to the atmosphere. Thus, after two or three days, planktonic organisms were subjected to primarily residual constituents of low toxicity.

Approximately 500,000 gal of dispersant were used during 14 days of sea spraying operations. For the area treated, it was estimated that the concentration of detergent ranged between 1 and 10 ppm through the surface 5 m of water.[5]

Zooplankton, which are the most active organisms of the plankton, undergo marked vertical migration and might conceivably avoid toxic surface waters by swimming downward. However, the more passive organisms, i.e., diatoms, dinoflagellates, and the embryonic and larval stages of invertebrates and fishes could be subjected to the above conditions for protracted periods of time.

Laboratory experiments verify that the toxicity of the oil spill dispersants in sea water is largely restricted to the rapidly evaporative organic fractions and that most smaller planktonic organisms are killed in a matter of a few hours at concentrations of 1-10 ppm[5]; however, there was evidence of a longer-term effect on certain of the organisms tested, manifested twelve days after exposure to concentrations of 1 ppm.

Although plankton life forms appear to be extremely sensitive to dispersant, their destruction within the finite sea volumes associated even with massive oil spills is of lesser consequence because of their capability for rapid repopulation. Destruction of the larval and embryonic stages of fishes, however, are likely to have severe long-term effects in terms of depletion of commercial and recreational fisheries.

The majority of damage to marine life from the TORREY CANYON disaster was the result of applying dispersants on or near shorelines. The offshore spread of the dispersants and dispersant-oil mixtures caused extensive damage to intertidal animals and plants and killed or affected organisms at considerable distances from shore[5].

The increasing demand for treatment measures for dealing with oil pollution prompted the development of low toxicity dispersant chemicals. One such product is called BP 1100. It has been reported that the toxicity of this product is so low that it does not damage marine life[17]. BP 1100 has been demonstrated to be equally useful for dispersing sea-borne oil as well as oil-soaked beaches. Another dispersant with similar qualities has been developed and is distributed under the name of Dispersol OS. An additional low toxicity dispersant is Corexit 7664[18]. Toxicity tests have shown that concentrations for 48 hour $LC_{50}$ of Corexit 7664 was 7,500 to 10,000 ppm. This is the concentration of the dispersant which killed 50% of the test organisms in 48 hours. Similar toxicity tests for Dispersol OS and BP 1100 revealed 48 hour $LC_{50}$ concentrations of 3,300 to 10,000ppm[16].

## Effects of Spilled Oil on Property

The effects of spilled oil on property are almost inversely proportional to their effects on marine life. JP-5 will leave very little residue on beaches, vessels and structures with which it comes into contact. It can usually be easily washed off surfaces with water, or water with a small amount of detergent added. The slight residue which it leaves on sand and beaches goes away fairly rapidly under the influence of natural oxidation and bacterial action. The heavier fuel oils, however, present a vastly different situation. The effects of the two heavy fuel oils are much the same except that the Bunker C is worse than the Navy Special since it is heavier and more viscous and adheres to a surface more tightly once it becomes attached.

Removing Bunker C Fuel Oil from pilings, ship hulls, beaches, buildings, or rocks is an expensive and time-consuming operation. The damage is almost entirely esthetic except when the heavy oil plugs openings in a structure or hull, and this means that its removal must be complete to be successful. Bunker C is relatively resistant to the action of detergents and solvents since it is quite dense and very viscous. Sand blasting has been used successfully in cleaning it off rocks, but cannot be used on fiberglas hulls or wooden structures. Steam cleaning or hot water is also limited in application.

All four of the petroleum products considered are very harmful to objects made of natural rubber and some plastics. The damage in these cases results from chemical and/or solvent action and the danger is greater from JP-5 and Distillate Fuel than from the heavier, more viscous fuel oils.

## B. REFERENCE ENVIRONMENTS AND GEOGRAPHY SELECTION OF REFERENCE ENVIRONMENTS AND GEOGRAPHY

The geographic and environmental extremes to which U. S. Naval oilers and gasoline tankers are exposed are widely varied. Only those that are classified as adverse relative to an oil spill incident will be considered for this study. A near shore spill incident has much more serious implications than a mid ocean spill due to the potential for damage to both wild life and resources. For most of the world shore lines, recreational resources are confined to populated areas in the relatively warmer latitudes and are predominantly recreational beaches, small craft boating areas and sport fisheries. Other resources include but are not limited to commercial shellfish, commercial fisheries, salt production and minerals. Utilization of these resources varies greatly for a number of reasons, some of which are population density, logistics, technology and industrial capabilities.

The two most significant factors that influence the migration of spilled oil in a marine environment are local winds and surface currents. Of these two factors contributing to oil migration on the surface of the seas, the local winds will be the predominant consideration for both potential hazard to shore lines and urgency for remedial action. Coastal winds are significantly influenced by convection circulation. For example, air in the day time over the land masses will be heated and rise to be replaced by the cooler, more dense atmosphere from over the sea. During the hours of darkness, the process may reverse to cause a seaward circulation. This effect is created by the temperature differential between the sea mass and the land mass and is of course heavily influenced by local weather, season and geographic latitude. The effect of tidal flushing on local currents associated with open coastal coves and bays is widely varied ranging from strong in large narrow bodies of water such as Cook Inlet in Alaska and the Norwegian fiords to weak in open bays such as Kawaihae Bay on the Island of Hawaii.

Detailed information obtained during the course of this study on geographic, meteorologic, hydrographic and resource features is given in Appendix A.

Because the potential routing of United States Naval vessels worldwide is virtually infinite, climatological data will not be presented for specific routes. Figure Nos. A-1 through A-8 (Appendix A) are reprinted from the U. S. Navy Marine Climatic Atlas of the World, Volume VIII. The data is presented for sea, swell, and wind velocity for each of the four seasons of the year. In the presentation of frequency of occurrence of sea heights, the term "sea" refers to those waves generated by local winds while "swell" is that portion of

the wave spectrum far removed from its source region. For winds, the percent frequency of occurrence is presented for Beaufort Force Eight and above and Beaufort Force Three and below.

Table 3 summarizes pertinent environmental and resource data for reference regions of open waters. These are the reference areas for the determination of parameters in connection with the effectiveness studies, and for the assessment of resources vulnerable to damage by petroleum product spillage. These reference areas were selected as those typical of open waters frequented by U. S. Naval oilers and gasoline tankers.

## OIL POLLUTION REGULATIONS AND ENFORCEMENT

There has been a great deal of effort at both the state and federal level to provide more clearly defined and more stringent regulations relative to water pollution in U. S. waters. The most significant of the new legislation is public law 91-224 which is titled the "Water Quality Improvement Act of 1970." This new measure authorizes the Federal Government to move immediately to clean up harbors or beaches devastated by an oil spill using funds from a new 35 million dollar revolving fund. The act further fixes the liability of the owners of offshore facilities or vessels responsible for a spill at up to $8,000,000 for an offshore facility and $100 per gross registered ton or $14,000,000 whichever is the lesser amount for a vessel except where an owner or operator can prove that the spill was caused solely by an act of God, and act of war, a third party or negligence on the part of the United States Government. Additionally any person in charge of the vessel or facility shall be fined not more than $10,000 or imprisonment for not more than one year or both for failure to immediately notify the appropriate federal agency. A civil penalty of $10,000 for each offense may also be imposed on any owner or operator of any vessel, offshore facility or onshore facility who knowingly discharges oil into or upon the navigable water of the United States, adjoining shorelines or contiguous zone.

Great Britain and eight other countries signed the North Sea Pact in March 1969. As a result of this pact, the Board of Trade has been charged with the responsibility of dealing with oil on the seas in excess of one mile from United Kingdom coasts.

The continuing efforts of the council of the Intergovernmental Maritime Consultive Organization (I.M.C.O.) are providing more impetus toward imposing additional international regulation that would minimize the potential for marine oil disasters. Some of their recommendations include the compulsory carriage of radar, echo sounders, radio position plotting equipment and VHF radio communications equipment. Some other committee considerations are training courses, ship design and compensation for loss or damage arising from an oil spill. In November 1969, I.M.C.O. sponsored an International Legal Conference on Marine Pollution Damage in Brussels where it adopted two conventions. The first convention, which applies only to incidents occurring outside the territorial limit, would allow coastal states to intervene in oil spill casualties if their shorelines are threatened by the incident. The second convention imposes strict liability on owners and operators with certain exceptions including acts of God, war, and negligence of the coastal state. Limits of liability are set at $134 per gross registered ton or $14 million, whichever is the lesser. Compulsory financial responsibility would be required with issuance of certificates to this effect. The conventions do not apply to warships or other state-owned ships, except when they are on commercial business. These conventions must first be

Table 3. Data Summary–Reference Environments and Geography

| | Environmental Characteristics | | | Resources | | | | |
|---|---|---|---|---|---|---|---|---|
| Area | Expected Wave Height 90% of Time | Max. Wind Velocity 90% of Time | Mean Sea Temp. °F | Recreational Beaches | Boat Marinas | Sport Fishery | Commercial Fishery | Commercial Shellfish |
| Astoria, Ore. | 3.3 Ft. | 14 Knots | 53.9 | Yes | Yes | Yes | Yes | Yes |
| Eureka, Calif. | 1.8 | 11 | 52.9 | Yes | Yes | Yes | Yes | --- |
| San Francisco, Calif. | 5.3 | 17 | 55.6 | Yes | Yes | Yes | Yes | Yes |
| San Diego, Calif. | 1.0 | 9 | 61.4 | Yes | Yes | Yes | Yes | --- |
| Massachusetts | 6.1 | 18 | 47.8 | Yes | Yes | Yes | Yes | Yes |
| Charleston, S. C. | 3.3 | 14 | 68.0 | Yes | Yes | Yes | Yes | Yes |
| Norfolk, Va. | 4.6 | 16 | 60.2 | Yes | Yes | Yes | Yes | Yes |
| Hawaii | 5.3 | 17 | 72.8 | Yes | Yes | Yes | Yes | --- |
| United Kingdom | 13.0 | 26 | 53.3 | Yes | Yes | Yes | Yes | Yes |

ratified by each I.M.C.O. member. When ratified, they become binding internationally. The coastal states' intervention becomes binding when 15 member governments ratify the convention, and the civil liability convention becomes binding after eight I.M.C.O. member states ratify the convention but five of the eight must have more than one million tanker tonnage each. There are 68 member governments involved in I.M.C.O.[19]

## C. OIL SPILL TREATMENT AND RECOVERY EQUIPMENT AND TECHNIQUES

Countermeasures against oil spilled on the open sea can be classified as:

- Mechanical: skimmers, pumps, spreaders, collectors, booms and weirs.
- Chemical: emulsifiers or detergents, combustion promoters and biological degradation agents.
- Chemomechanical: sinking, sorption, agglomeration, chemical booms and others, all, with the exception of sinking, being accompanied by a mechanical recovery technique.

Mechanical treatment of oil spillage is defined as treatment which operates by purely physical means, thus not requiring consumption of materials. Chemical treatment depends upon chemical properties of agents; oil and agent interact to remove an oil slick from the surface. Chemomechanical treatment will logically be the hybrid combination of the classifications. Consumables as well as mechanical equipment may be utilized in the removal operation.

Three distinct operational areas can be identified which would use chemical, chemomechanical or mechanical methods. They are:

- Containment
- Physical/Chemical Elimination of the Slick
- Disposal of Recovered Products

Techniques applicable to each area are described below.

Containment

Deployment of any type of barrier controls the direction and limits the spreading of an oil slick. Booms may be passive or dynamic. Containment booms are passive. Dynamic techniques are used for moving slicks from one area to another or from an area to a collection device.

The advantages of containment include:

- Preventing an oil slick from contacting items of economic or aesthetic value.
- Reduction of the water surface area subsequently processed by some removal technique.
- Preventing the spread of oil, thereby making some removal techniques, which perform best on thick slicks, more feasible.

Containment is not without disadvantages. Solid barriers prevent crossing by equipment or vessels. The confinement of oil slicks containing large quantities of highly volatile materials may create a fire hazard.

The sources of most accidental oil spills will approximate a point source, either moving or stationary. The spreading pattern emanating from a point source may be an expanding circular disc, an elliptical shape or an expanding triangular shape, depending on surface

currents and winds. A circular slick is formed by an unrestrained source in an area of no significant surface currents and wind. An elliptical slick will occur when a surface current is present but of a smaller magnitude than the spreading velocity of the oil slick itself. Triangular shapes occur under high current situations where the current dominates the spreading of the slick. The triangle will widen as the slick distance from the source increases. For all cases, wave action is expected to perturb these shapes, eventually forming windrows or ropes of oil.

The containment boom can be used to advantage in confining the oil released in each of the cases described. For the circular or elliptical shaped slick, the boom must maintain a continuous circular barrier. The triangular shaped slick can be constrained by a lineal boom positioned in a catenary shape directly opposing and down current of the moving oil slick. This is the most difficult condition for recovery purposes because of the relatively high current which must be opposed–a much shorter boom is required, however.

The general areas of application for oil booms are for oil recovery operations and for emergency containment. Oil recovery operations can employ booms for dragging or sweeping operations as well as reducing the confinement area by gradually decreasing the perimeter. The effectiveness of such sweeping operations is questionable and is discussed later in this section.

Development of seaworthy and more effective booms for open sea applications, such as around oil drilling platforms, is being attempted. Contributions are being made by manufacturers in trying to capitalize on demand for open sea booms. The Coast Guard is also supporting several projects to develop open sea, easily deployable booms. The American Petroleum Institute and the Federal Water Quality Administration are also supporting boom development for open sea application.

Containment barriers are classified as:

- Floating booms
- Pneumatic barriers (underwater air barriers)
- Chemical barriers
- Powered booms

Floating booms are much more extensively employed than the other types.

## Floating Booms

Floating booms are commercially available in a wide variety of sizes and configurations or can be fabricated from any number of available materials such as wooden timbers, used 55 gallon barrels, fire hoses, etc. A list of commercial booms is included in Appendix C.

An effective floating boom must provide a vertical barrier at the water surface, extending above and below the water surface. The barrier is commonly formed by combining a bouyant section with a rigid or weighted skirt extending downward into the water. The buoyant portion consists typically of either an inflatable bladder or buoyant material such as plastic foam, cork or wood timbers. Skirts typically consist of metal, plastic sheet or rubberized fabric with lead weights or steel chain providing ballast at the bottom edge.

Makeshift booms such as wooden timbers or inflated fire hoses generally lack skirts and, therefore, effective usage is restricted to waters that have little or no surface currents or waves and to spill situations in which the contained oil does not reach an appreciable

thickness. Skirts of extended draft are necessary in the presence of surface currents to impede the oil from being swept under the boom as it accumulates. An oil slick floating against a barrier behaves much like an iceberg in that about 90% is below the mean elevation of the surrounding water, depending on the density of the petroleum product. In the presence of currents, a thick wave of oil forms at the upstream edge of the oil layer which leads to the formation of oil droplets when the water flows faster than a certain critical speed. These droplets may then be swept under the barrier. Experiments observing this phenomenon found oil swept under 6 to 12 inch skirts at 0.85 ft/sec and above. The speed required for oil carryunder varies with the oil properties, barrier dimensions, and amount of oil being retained[20].

Oil can also go under a boom by a draining action. Water flowing under the barrier causes a pressure reduction which could pull the oil under it. Wick[20] has calculated the minimum skirt depths to prevent draining for several conditions. This depth can be as great as 94 inches for an oil with a specific gravity of 0.97 and a viscosity of 9,215 centipoises being collected at 5 barrels per foot of boom in a current of 2.25 ft/sec.

The constraint of sweeping speed upon booms has been investigated by J. Wardley Smith[21]. Field tests show that oil carryunder occurred at a sweeping speed of about 2 knots (large boom with 18" diameter buoyant section with a 3' attached skirt). Model scale tests at the Hydraulics Research Station found just over one knot was enough to lose oil. Smith's[21] conclusions were that anything above one to two knots current and waves higher than about 6 inches will remove oil from a boom of this type.

Theoretical considerations indicate that the holding capacity of a boom increases by the cubic power of the boom depth[22]. An example evaluation of a hypothetical situation was made by Hoult[22]. It indicates the shortcomings and limitations of a generalized boom for an analytical approach. The situation is a 100,000 gallon spill in an estuary, a boom 200 feet long with a three foot holding capacity being deployed. It was found that oil would be carried under if the wind velocity exceeds 12 knots normal to the boom with no waves present, or if the water surface current normal to the boom exceeds 1/3 knot. The effect of waves would further reduce these threshold values.

Flexibility and structural strength are other requisites of an effective containment boom. Flexibility permits the boom to follow the profile of the water surface. Satisfactory flexibility can normally be obtained either by employing flexible materials, such as foamed plastics, for the buoyant section or short sections (not more than a few feet long) of relatively rigid materials connected with flexible joints. Boom tension may inhibit the wave following capability of flexible booms, however.

Emergency containment booms require a relatively great structural strength, especially if they are to be towed to the scene. Permanent booms can be moored in place to minimize environmentally induced forces. Emergency containment booms often must be positioned and held with ships which can, in combination with the environment, induce significant forces.

Deployment considerations require that an emergency containment boom be either capable of being towed at speeds up to about 10 knots or deployable from the deck of a vessel at the site of the incident. Floating booms with sufficient flexibility can be stored on drums from which they can be unreeled for deployment. Many commercial booms can be folded on a pallet, like an accordion, for storage.

Floating booms employing air-filled chambers for buoyancy, although less expensive than other types, are not recommended for emergency situations because of susceptibility

to puncturing and subsequent sinking. This type of boom in harbors can, however, be satisfactorily employed as a permanent boom such as around ships or other areas susceptible to spills.

Experience at the recent Gulf Coast spill indicates that the Navy type booms made of plywood sheets covered with canvas were the most effective means of coping with a large oil spill. Chevron improved upon the original U.S. Navy design somewhat using 4' x 8' sheet of 3/4-inch marine plywood with two 55 gallon drums attached to each side of the sheet. Canvas sheets with attached counterweights produced a boom of a total height of 7 feet.[23][50]

## Pneumatic Barriers

Pneumatic barriers (underwater air barriers) can provide a sufficient surface current to contain oil spill in harbor waters if winds and surface currents are not excessive. The operation entails injection of air through a perforated hose or pipe into the surrounding water at a given depth. The bubbles formed create a buoyant air/water mixture which rises to the surface. The vertical motion of the water produces a surface current flow in both directions away from the line of air emergence. Surface currents up to five ft/sec can be produced by injecting up to 90 SCFM of air per foot of length. Standard air compressors (nominally 100 psi) are generally used to provide air. The advantages of pneumatic barriers include:

- Unrestricted passage of ships across the barrier.
- Relative immunity to environmental forces.
- Invulnerability to fire.
- In certain instances, such as when the barrier is biased across the direction of water flow, the oil can be guided to a single location to facilitate pickup.

Disadvantages include:

- High procurement and operational costs.
- Possible penetration of accumulated oil as ships pass across the barrier.
- Complete negation of the effectiveness in the event of power, compressor, or pipe failure.

Pneumatic barriers must essentially be custom designed for each particular application. They have therefore been permanently installed rather than used as portable emergency containment devices.

## Chemical Barriers

Chemical barriers can be formed with fatty acids spread at the periphery of a spill. The high spreading force of the fatty material will repel the nonpolar petroleum oil and displace it into a thickened oil lense or away from the agent in the case where the spill is not surrounded. The agents function by counteracting the spreading tendency of the spilled oil.

Garrett[24] and Canevari[11] suggest that it is the surface active constituents of the spilled oil which cause an otherwise nonspreading hydrocarbon to spread. Special monolayers have been identified by Garrett[24] which have quite high spreading pressures. They have been found to be able to spread against the wind in some cases and to support oil lenses of spill material on the order of 0.5 to 1.0 cm in depth. The lense thickness which can be maintained depends on the oil density and the difference in spreading pressure between the spilled oil and the monolayer. Monolayer water-insoluble films would probably find greatest use against relatively minor spills along coasts or in rivers and harbors[24].

Chemical gelling agents, if spread around the periphery of an oil slick, could also impede the spreading of the slick due primarily to a viscosity increase of the oil/gelling agent combination.

It is likely that chemical barriers would be effective only in reducing the initial spreading of oil slicks and not as a long term containment technique. Chemical barriers may have an application in support of other possible systems.

### Powered Booms

At the present time, no available containment booms operating on the open sea use a self-contained power source. Advance concepts employ air or water as a motive force to move surface oil slicks. Water surface currents are created which counter those induced naturally by wind or waves. The Federal Water Quality Administration (FWQA) is sponsoring a boom concept with Batteile-Northwest which employs a water spray technique for sweeping.

## PHYSICAL/CHEMICAL ELIMINATION OF THE OIL SLICK

The treatment of an oil slick can be accomplished by a number of methods, ranging from purely chemical approaches, as in the use of detergent materials, to mechanical methods such as skimming and suction devices. Containment, as described previously, is a complementary function to the actual treatment of the slick. One exception is a boom configuration as an essential part of certain basic skimmer concepts.

The elimination of the oil slick is the overriding objective of all oil spill abatement methods. This function is an integral part of any system of spillage countermeasures. Containment as well as disposal of collected residues are functions which are unnecessary in some cases and subordinate to the oil slick treatment in all cases.

### Mechanical Treatment

The physical recovery of oil or agglomerated mixtures of oil and various agents can be achieved with mechanized equipment designed for the recovery of petroleum or similar materials from the sea surface. Mechanical treatment includes such techniques as:

- Skimming with a suction device
- Rotating drums or endless belt-pickup devices
- Skimming with a weir
- Ancillary equipment

Suction Devices - Petroleum products can be either lifted or skimmed from the water surface with a variety of vacuum or suction devices. The general class of devices is only effective on relatively thick slicks with most requiring partial or total immersion of the nozzle in the oil. A considerable amount of water may be recovered with the oil and, therefore, the systems often employ gravity separation or decanting tanks as a secondary operation.

Heavier oils such as Bunker C and debris tend to clog intake lines and render many suction devices inoperable. Another operational difficulty that can be encountered, depending on the type of pump used and whether or not the oil passes through the pump impellor is that of emulsification of the oil. A water-in-oil emulsion is easily formed by pumping oil and water through a centrifugal pump. Once formed, this emulsion is most difficult to break-back due to its stability and semi-solid consistency.

One type of suction device that recovers a high proportion of oil (assuming ideal conditions) is an airlift system. The system utilizes the principle that a high velocity stream of air moving over the surface of a slick and into a suction nozzle will entrain the oil from the surface. A bell-mouth nozzle is suspended approximately one inch above the water surface. The nozzle or ejector employs the high flow/low vacuum characteristic of a Coanda nozzle. The use of a water vortex below the nozzle is a method used to assist this type of device.(25)

Rotating Drums and Endless Belts - Numerous devices that employ some configuration of rotating drum or endless belt are either currently available or being developed. The oil is removed from the water surface by the natural oleophilic properties of the advancing surface of the belt or drum. The oil that adheres to the moving surfaces may be subsequently scraped off by a blade. Units employing hydrophobic plastic foam socks or other sorbent materials require squeezing by rollers to recover the oil. Another type of unit akin to an endless belt system employs long rolls of sorbent material, such as felt, which retains the oil for subsequent disposal.

One rather unique configuration presently being developed by the Shell Oil Laboratory (Netherlands) and Murphy Pacific Marine Salvage Company employs a very large continuous loop of sorbent material such as polypropylene "wool." Recently tested at Treasure Island (San Francisco), this device is operated by moving this continuous absorbent belt through an oil slick between two pulleys and squeezing the oil from the belt using wringers mounted on a ship or at a shore facility.(26) (50)

One recently developed device employs two counter-rotating drums. One is rotated at a relatively high speed in the direction of water flow. A shallow immersion depth on this drum makes it effective for removing heavy, weathered oils. This drum may have a polyethylene surface which comes in contact with the oil in a dry condition and thus becomes oil-wetted. The other drum rotates slowly opposite to the water flow direction and is immersed relatively deep. The drum has a water-wetted steel surface which is more effective on lighter, less viscous oils.

In most cases, the rotating drums and vertically oriented endless belt devices are ineffective in wave heights exceeding about six inches because the oil must come in contact with oil-wetted surfaces for effective removal. Waves often disturb the surfaces before contact with the oil is made. The proportion of oil to water recovered generally exceeds 90% when water surface conditions are not excessive. These units are most effective when advancing at very low speeds. Present units are generally not highly maneuverable and are incapable of recovering large quantities of oil.(27)

Gravity Skimmers Employing Weirs - Several Naval facilities currently use skimming devices based on the concept of an advancing weir. The facilities include the Puget Sound, Long Beach, Norfolk, and Pearl Harbor Naval shipyards and the Newport, Rhode Island Naval Station.

The Puget Sound and Newport units are converted LCMs with an adjustable lip or weir at the forward end. The Pearl Harbor LCM is not an integral unit; auxiliary skimming rafts are towed alongside. Storage/decanting tanks permit separation of the oil from the recovered mixture. A three-man crew is required on the Puget Sound Naval Shipyard unit; the constant attention of one of these members is required to adjust the height of the weir. The Norfolk and Long Beach skimmers are similar to the converted LCMs but considerably smaller. The Norfolk unit is not self-propelled. Storage capacity of the skimmers ranges from 6,000 to 10,000 gal. Recovery rate of the Norfolk skimmer is reportedly 600 gal/hr under optimum conditions.

Another gravity skimmer that employs an advancing weir is the WATERWISSER, developed by Shell Chemicals in Holland. Extendable booms on each side of the craft increase the scope during each traverse of an oil slick. The unit can operate at forward speeds up to about two knots. The recovered mixture enters a sump through a vertical slot extending approximately one foot below the water surface. The mixture is subsequently decanted and the water pumped overboard. Oil storage capacity is 20 tons.

Gravity flow or advancing weir devices are generally sensitive to environmental factors, particularly waves. One disadvantage of large self-propelled units is that routine maintenance or breakdowns can remove the unit from service possibly during a crisis situation. The Puget Sound Naval Shipyard unit was reportedly out of service for two months while repairs were being made.

Development work in the area of mechanical skimming is being supported by the American Petroleum Institute, the Federal Water Quality Administration, and the Coast Guard.

The "Sea Dragon" concept is under development by the Garrett Corporation, under support by the American Petroleum Institute. The basic concept is a coalescing box towed by a boom and cable arrangement attached to each of the two front corners. The booms are on the order of 500 feet long making it possible to sweep a 200 to 300 foot swath. The open front collection box will receive the oil. A series of baffles is used to still the water within the box and also allow the oil to be collected. An adjustable lip allows oil to be gathered and pumped to the Garrett Airesearch ultracentrifuge for separation. The prototype is expected to be tested in August 1970 off the California coast.

Skimmer barges were used with some success at the recent Gulf Coast spill by Chevron. They reported they worked well in up to 6-ft waves. The most effective operation involved the use of two tugboats at each end of a large barge. The tugs pushed the barge broadside against the oil. Several pumps aboard the barge sucked in oil and water. This effort produced an oil/water pickup rate of 27.7 bbl/min, more than twice the rate of any other skimmer.[23]

Auxiliary Equipment - Most oil slick recovery techniques employ auxiliary equipment which directly or indirectly influences overall system efficiency. Principal examples are: (1) mechanical spreaders, (2) hydraulic spray systems, (3) oil/agent recovery and retrieval equipment, (4) oil-water separators, and (5) oil/agent retention equipment.

(1) Mechanical spreaders include converted agricultural equipment in the form of bale shredders, straw spreaders and fertilizer or seed distributors. These and other mechanisms are used to take a solid material–sorbent or sinkant–break it up into the appropraite particle sizes and shapes (if necessary), and distribute this material on the slick. Straw and other sorbents are shredded and then distributed using converted haying equipment. Sinkants in the form of treated sand and other particulates are spread by mechanical broadcasters.

The use of air blowers may also be appropriate in distributing sorbent or sinkant materials although the dust which may be produced could irritate the respiratory systems and eyes of operational personnel.

(2) Hydraulic application of materials is appropriate to several types of operations. Chemical treating agents in a petroleum solvent base can be applied directly or as an emulsion in water. This emulsion is produced by flew through centrifugal pumps which provide intimate mixing of water and agent. Chemicals miscible in water can be sprayed directly using commercial sprayers, or they may be diluted using an eductor. Canevari[11] notes that application of water base dispersant in a water stream is effective, whereas application of a petroleum base dispersant in a water stream is not. This is because a dispersion of the petroleum solvent-in-water is formed, and it is difficult for the surfactant to transfer from its location at the petroleum solvent-water interface to the oil spill-sea water interface. Canevari concludes that neat application of a petroleum base dispersant directly to an oil slick is a more effective application method. Eductors can also be used to distribute materials underwater, i.e., certain sorbent materials. Sinking and burning agents may also be applied in a water stream.

(3) Oil and/or agent harvesting is a method by which sorbents, gellants or other materials along with oil are retrieved. By far, the most common technique is manual labor using implements such as pitch forks and rakes. This method is, however, impractical in large spills in the open sea environment. Environmental conditions permitting, kelp harvesting machines may be used for the retrieval of agglomerates of oil and various agents.

(4) Oil-water separators have been used for many years to remove oil from oily ballast water aboard tankers. These, as well as separators suited for use in oil spillage recovery, are described below:

- Gravity or Centrifuge Separation

As the density between the water and the oil approaches zero, so will the effectiveness of gravity dependent devices. A pump for oil recovery recently announced by the Reynolds Metals Company uses a combination of gravity and centrifugal force generated by the vortex axial flow path within the pump. A tube inserted in the center (forming an annulus) will draw off the oil while the sea water passes outside the tube. An 8-inch diameter pump will reportedly take in 2500 gal/min. Therefore, oil in a 10% mixture of oil to water, would be recovered at a rate of 250 gal/min.

- Sonic and Ultrasonic Energy

Ultrasonic energy may be employed to emulsify or demulsify oil and water.[28] This method may be used in conjunction with other separators for breakdown of water-in-oil emulsions. Sonics International, Inc. has performed a study for the FWQA which evaluates the possibility of emulsifying oil for transportation by tanker and then demulsifying upon offloading at a port.[28]

- Dialysis

Semipermeable membranes which pass oil but not water have very small pores and would be quickly fouled by solids. Separation of the oil by this method at a practical rate is impossible at ambient conditions.[29]

- Solvent Extraction or Dilution

Dilution can be used to reduce the viscosity and density of oil, possibly making it more easily processed by other separators. Solvents could also be used in extraction equipment to treat oily water. This method may be hampered by the difficulty in attaining intimate contact between the extraction fluid and the oily water, especially if emulsions are present.

- Dissolved Air Flotation

This method has been found to be effective but requires a significantly long retention time and large space requirements. This is one method by which oil is separated from refinery wastes. The Permutit "Favair" flotation system of oil separation uses this method.[30]

- Sorption

Surfaces treated to be oleophilic (attracted to oil) or hydrophilic (attractive to water) can be used to concentrate oil. Rotary drums or moving belts with provision for continuous oil removal by scraping, flushing or steaming is an extension of this method. This method is being used successfully in skimmers for harbor use. See Appendix C.

- Filtration

Many different materials have been used to remove relatively small amounts of oil from water, most of which rely on oleophilic properties to retain the oil as an absorbed film. The filter media could either be dumped or stripped for reuse.

- Coalescing Media

Agglomeration of oil behind or between screens can be accomplished using a suitable coalescing media. However, this method becomes ineffective when used on dirty or highly viscous oils.[29]

(5) Oil/agent retention equipment comprises tanks, barges, etc., which are used to contain oil, water and treating materials once they are retrieved from the surface. A device specially developed for this task is the dracone barge produced by Uniroyal, Inc. -- a 149 by 30 ft. mylar reinforced oval bag. It is collapsible for compact stowage on an air-drop pallet. Once on the sea, it is filled with up to 1,000 tons of oil. It can then be towed to disposal sites at five knots. This device and others of similar design are essentially flexible and portable coalescing tanks.

Another system in the oil-agent retention category is an air delivered anti-pollution transfer system (ADAPS) for debunkering stranded or incapacitated vessels. The system, developed by Ocean Science and Engineering, Inc. for the Coast Guard, is completely air deployable using HH-3 and C-150 aircraft. It uses 500 ton capacity nylon and rubber pillow tanks and utilizes a diesel or gasoline driven, hydraulically powered pump. The pumping rate is 250 tons per hour ( $\sim$ 70,000 gph). Crews put the system together for offloading from tankers or barges. The pillow tanks are filled and towed to shore facilities for subsequent disposal. The system is designed for towing at speeds up to 5 knots and can be employed in multiples where greater storage capacity is required.

At the successful completion of the air drop testing phase, operational development will be undertaken. The system is not considered available as yet, though it passed a public test 14 May 1970. The Coast Guard expects to train a special crew in the operation of this system. A limit of 300 miles of the shoreline is imposed on the system --the operational limits of the helicopter.

This concept has other functions worthly of mention: It can lighten a stranded vessel, making it possible to pull free. It can be used as a fire-fighting system on ships which have lost power. It could be a salvage tool to keep a crippled ship afloat.[31]

## Chemical Treatment

Chemical treatment methods involve one of the following:

- Dispersion with emulsifiers–an oil slick is transformed into an oil-in-water emulsion which diffuses three dimensionally into the water environment.
- Burning a flammable mass is formed by the addition of fire enhancing agents. The oil is burned and reaction products go to the atmosphere.
- Biodegradation–select microorganisms are applied to an oil slick. These organisms biologically oxidize the oil.

Dispersion with Emulsifiers - Oil dispersion with chemical emulsifiers is a common method of treating oil spills.

Hundreds of commercial dispersants are available for oil spill cleanup; a representative compilation appears in Appendix C. The function of these agents is to disperse the oil into a stable oil-in-water emulsion which will eventually degrade naturally in the body of water.

The majority of dispersants contain three constituents: surfactants, solvents and stabilizers. A typical dispersant is about 70-80% solvent, 10-15% surfactant, and 10-15% stabilizer. Compositions of some of the dispersants presently in use are listed below as representative but not inclusive of the possible combinations of constituents.[32]

| | |
|---|---|
| Detergent No. 1 | Soaps 30–50%; aromatic solvents 48–65%; inhibitors 2–5%. |
| Detergent No. 2 | Polyglycols – 20%; aliphatic solvent – 80%. |
| Detergent No. 3 | Polyethanoxy compound approx. 10%; isopropanol diluent approx. 90%. |
| Detergent No. 4. | Alkyl-aryl sulphonate 50%; aromatic solvent diluent 50%; no stabilizer. |
| Detergent No. 5 | Polyglycols – 9%, polyethanol – 18% aromatic hydrocarbons – 73%, no stabilizer. |

The surfactants may be ionic or non-ionic compounds such as polyethanoxys or polyglycols. The surfactants used for oil dispersion, unlike those employed in household detergents, are "hard": that is, they are not readily destroyed by microorganisms.[33] The surfactants effectively alter the surface tension and cohesive properties of the oil such that the oil tends to spread and form a colloidal suspension or emulsion.

Stabilizers are employed to preserve the emulsion and thus inhibit recoalescence. Solvents allow the surfactant to penetrate the slick and mix with the oil. Two general classes of solvents are employed: petroleum base and water base. Kerosene is a common solvent.

The dispersion of an oil slick by emulsification or complexing tends to promote a more rapid degradation because the surface area is greatly increased. However, this may or may not be true, depending on the constituents of the particular dispersant; some may inhibit natural biodegradation. Observations concerning the stabilitity of emulsions vary greatly, depending on the nature of the experiment. Oil tends to recoalesce on the surface in the absence of continued agitation or tidal flushing.

The amount of oil emulsified with a given amount of dispersant varies widely among products. Manufacturers' claims generally report from 5 to 100 parts of oil per part of dispersant. The amount dispersed varies with the type of oil treated, method of application, slick thickness, temperature, and environmental factors. However, a reasonable assumption for typical spills is that about one part dispersant is required to disperse five parts of oil.

Work done by the Naval Civil Engineering Laboratory[34], the Ontario Water Resources Commission[35], and others, indicates considerable variation in the effectiveness and toxicity of the various products tested. Further testing of additional properties of a greater number of products is clearly needed.

Many of the commercial products have been tested for toxicity to different species and under different conditions of water quality and specimen preparation. Results show acute toxic levels of from a few ppm to 10,000 ppm for the least toxic agents and most resistant organisms.

Chemical dispersants have a high biochemical oxygen demand. Each gallon of emulsifier has the same adverse effect on the oxygen balance of water as about 2500 gallons of crude sewage.[36]

The choice in the use of an emulsifier may be between high cost, less toxic and less effective agents and lower cost, highly toxic and more effective agents. The determining factors in making the practical choice of an emulsifier within these extremes are: (1) oil type and thickness, (2) cost, (3) the amount (concentration) of emulsifier which is necessary to do an effective job on the oil slick, and (4) the expected immediate and long term toxic effects of the emulsifier and oil upon the bioenvironment of the spill location.

Burning - Combustion promoters may have any or all of the following constituents: igniting substances, substances which maintain combustion, and substances which assist combustion. Burning effectiveness is influenced by the spill environment–oil type and thickness, wave and wind conditions and temperature of air and water.

Significant amounts of water emulsified in the oil will greatly influence the ability of an oil slick to maintain combustion. The retained water must be released from the oil or vaporized with the combustion products. The latter requires heat from the combustion, thus impeding the oil burning.

Volatile constituents necessary for the combustion processes may be diluted due to winds. Spray generated by wind or propulsion wakes may also impede burning.

Experience during the TORREY CANYON spill showed burning agents available at the time to be of questionable value in other than ideal conditions. The ARROW spill of Nova Scotia (1970) related that the product, "Seabead" (a cellated glass bead product), will permit oil to be burned on the shoreline as well as on the open sea but that it is desirable to accomplish this burning promptly and prior to extensive emulsification.[37] These conclusions were based upon small slicks (35 ft dia) in 35° F air temperature and 1-1/2 ft waves. Containment devices were not used for these tests on Bunker C of unknown composition and weathering.

Recent sea trials (May 1970) off the Atlantic Coast for the 1st Naval District employed "Seabead" and a silicon dioxide powder ("Cab-o-Sil"). Both products functioned to burn an estimated 10,000 gallons of a 15,000 gallon created spill of Bunker C. The amount each burned is undetermined; however the silicon dioxide powder burned for about 16 minutes and the cellated glass bead for 4 minutes in swells of 8 to 10 feet and seawater temperature of 44° F. Some difficulties were experienced from wind action in applying the powder materials. The material is entrained in a water stream, but is unwetted and can separate and be blown about by wind action. The destroyer's prop wash tended to extinguish the fire. This was corrected by backing away after oil ignition. The test was also verified that Bunker C cannot be ignited without the use of burning agents.[38]

Biodegradation - Agents of this type have been used in the treatment of refinery effluent and other waste streams, but not for large scale open sea situations. Biodegradant organisms are present in all facets of nature and represent the major mechanism in the eventual reduction of oil from the persistent viscous glut to useful metabolizable constituents.[39] Organisms have been developed which concentrate specifically on the biological breakdown of certain chemical groupings, chemical bonds or petroleum types. A particular organism would be expected to be more effective on some petroleum components and relatively ineffective on others.

The rate at which microorganisms oxidize hydrocarbons is influenced largely by the dispersion and solubility of the hydrocarbon and by the water temperature.[40]

"Based upon rates at which marine bacteria have been observed to oxidize various kinds of mineral oils under laboratory conditions and upon information on the abundance of bacteria in the sea, it is estimated that oil might be oxidized in the sea at rates as high as 100 to 960 mg/m$^3$ day or 36 to 350 g/m$^3$ year."[12]

Chemomechanical Treatment

Those methods which employ both mechanical and chemical mechanism are:

- Sinking--A dense material is used to agglomerate or sorb the oil into a mass which sinks.
- Sorption–Materials which absorb or adsorb the oil are spread upon an oil slick, thus forming a mass which can be mechanically harvested and subsequently disposed of.
- Gellation–Chemical materials applied to an oil slick produce a semi-solid residue which is mechanically harvested and subsequently disposed of.

Sinking - Several materials have been employed to sink oil slicks from water surfaces. Carbonized sand has been employed extensively by the Navy for this purpose. Carbonized sand is manufactured by mixing beach sand and creosote and subsequently heating the coated sand to approximately 800°F in a furnace from which air has been excluded.[41] It can also be made by another method recommended by Midland Silicone Ltd. (England). A silicone product, DriSil 37, is applied directly to sand or pulverized fly ash.[42] The resultant product has an affinity for oil and repels water.

Sinking agents can be efficiently employed on thick or weathered oil slicks; it is doubtful that sinkants are effective on thin films and light crudes.[43] There are three principal disadvantages to the employment of sinking agents: (a) turbulence caused by storm conditions or ships passing shallow areas tends to release sunken oil, (b) benthic organisms in the form of fish, shellfish and plant life could be covered and destroyed, and (c) transporting and proper application of the sinking agent are difficult. The advantage of using sand as a sinking agent is that it is readily available at coastal locations by sea dredging and could be treated at or near the site of oil spills by shipborne or portable equipment. This would significantly reduce the necessity of transportation and storage of large quantities of material. Sinking agents, which have been employed, include:

| | |
|---|---|
| Sand | Vermiculite |
| Brick dust | Crushed stone |
| Fly ash | Slaked lime |
| China clay | "Stucco" |
| "Omya" clay | Coal dust |
| Volcanic ash | Chalk |
| Silicone mixtures | |

The application of sinking agents in harbor and near shore areas is not recommended unless the prevention of an immediate fire hazard is required and other more satisfactory means are not available. FWQA recommendations on the use of sinking agents are contained in Appendix F.

Tests in April of 1970 were made by Royal Dutch Shell using the sand-sink process of sinking open sea oil slicks. A mixture of treated sand and sea water is applied to the slick by a specially designed seagoing dredger. Some 10,000 to 15,000 tons of oil per day may be sunk at a low unit cost. The method is primarily applicable to massive cohesive slicks which are 1 to 2 mm thick. Laboratory tests have indicated that some oil returns to the surface in the first few minutes, the remainder stays down at least for a period of months. Toxic effects on benthic organisms and biodegradation rate information have not been determined. Laboratory development as of 1968 indicates a preliminary estimate of overall cost of the method of around $5/ton of oil sunk. The Working Party of the I.P. Coordinating Committee is studying oil sinking methods.[44]

Sorption - Floating sorbent materials include natural and synthetic materials which have an affinity for petroleum products and do not have an affinity for water. Sorbents are normally employed as part of a recovery system to prevent the spreading of oil slicks and to facilitate recovery.

The straw from wheat stalks has been the most extensively used sorbent for harbor spills because of its low cost and almost universal availability. The amount of oil sorbed varies with the type of petroleum product but is reportedly 4-5 times its own weight for typical crude oils.[15] Another source reports that straw will sorb between 8 and 30 times its weight of oil.[45] Straw would be the most effective on Navy Special and Distillate Fuel and least effective on Bunker C and JP-5. A list of commercial sorbents and other materials used for oil spill treatment is included in Appendix C.

One type of sorbent which holds great potential promise is high molecular weight polymers such as polyurethane, polyethylene, polystyrene, and polypropylene. These materials would normally be applied as a soft foam from which the petroleum product could be recovered by squeezing. Polyurethane can theoretically absorb 90% of its own volume and 100 times its own weight of oil, although difficulties have been experienced with absorbing heavy and weathered oils. Small scale comparative tests of several soft foams of high molecular weight polymers indicated that polyurethane was superior, followed by polypropylene and nylon.[33] Chemical treatment with additives such as silicone could enhance the oil absorbing characteristics of these polymers. If means can be developed to effectively recover and dispose of agglomerated mixtures of oil and sorbents, this method may become a significant countermeasure against open sea oil spillage.

Most floating sorbents require mixing or agitation with the oil on the water surface for maximum effectiveness. Little or no toxicity to marine life results from the employment of most sorbent materials.

Gellation - Gelling agents are used to congeal oil slicks by spraying the product directly on the oil. The method is relatively expensive with presently utilized products because the application ratio is, at best, one to one. The congealed mixture also can complicate recovery with many present mechanical devices because the oil is thickened considerably and is thus less amenable to pumping and gravity separation from the sea water. More advanced harvesting methods must be developed in order for this mechanism to be used successfully for large open sea oil spills.

One gelling concept which may be pertinent in this context is a technique being developed by Sonics International, Inc. The technique employed here is a preventative approach and not a removal concept, per se. Several oil types have been found to be readily emulsified by the use of ultrasonic energy in the presence of small quantities of detergents.

Sonics International, through an FWQA research grant, has tested the concept of emulsification (gelling) of oil, subsequent transportation and then breakback of this emulsion once in the delivery port. The emulsion of oil in water, approximately 98% oil, 1% water and 1% detergent, has a high viscosity and is found to be quickly eroded in an open sea spill situation, relieving the necessity of treating a surface spill.[28]

Disposal of Recovered Material

The disposal of recovered petroleum products, particularly if mixed with sorbents or debris, can be extremely expensive if nearby facilities are not available. Most recovered oil mixtures can be consumed as fuel in industrial or ship power plants that have special provisions for this source of fuel. Most Naval shipyards and other Naval facilities recover petroleum products from other operations such as tank cleaning and, therefore, have limited disposal facilities available.

Recovery of products in areas where normal disposal facilities are not available or from massive spills where facilities are inadequate, necessitates disposal at inland sites.

Sorbent or gellant mixtures with oil cannot be pumped and, thus, require loading into containers or dumptrucks for ultimate disposal by burning or at landfill sites.

Such sites must be carefully selected to insure that contamination of groundwater does not occur and environmental factors such as heavy rains or storm runoff do not pollute the area outside the disposal site. During handling, transfer, or storage of agglomerated mixtures, it is often advisable to cover the area of operation with plastic sheets to prevent contamination of shoreside areas.

Another alternative is burning, but the smoke generated is very objectionable unless high temperature furnaces are used. Agglomerated mixtures of sorbents or gellants with oil cannot normally be burned without a considerable drying period due to the water present in the material.

"Clean" oil obtained from mechanical skimmer or suction devices is generally of a sufficient quality for resale to refineries or tank cleaning establishments. This oil can be handled by vacuum tanks such as those used for septic tank cleaning.

Swift (1969)[15] related experience of disposal at the Santa Barbara Channel spill. Oil, sorbent and contaminated beach sand were disposed of by all three methods described previously. The total cost of landfill disposal was estimated at $4/cu. yd. Some in-place burning was accomplished but was abandoned in the later phases of the cleanup, possibly due to voiced complaints of the smoke and odor. Small quantities of clean, skimmed oil were trucked to local petroleum company facilities. The skimmed oil was blended with oil field stocks in the normal process feed stream. Some problems in equipment fouling were presented by the heavy, thick crude.

It was found from the Santa Barbara experience that waste disposal was a major and relatively expensive operation that required considerable planning.

Also, "The lesson to be learned here is that, in the event of another major oil spillage incident, the problem of disposal of waste oil and associated material can be a significant problem. This can be of even increased concern in areas where water supplies are dependent upon groundwater sources."[15]

## D. EFFECTIVENESS ANALYSIS

Analysis of the effectiveness of systems for removal of petroleum product spills from open sea water surfaces requires assessment of operational aspects under a range of conditions. These conditions are parameters whose extremes are the boundaries for the assessment.

"Effectiveness" is not quantifiable unless specific characteristics which contribute to or detract from the overall effectiveness are considered. The identification of such characteristics, criteria for judging them, and a rational plan for combining them into overall effectiveness follow.

### EFFECTIVENESS PARAMETERS

Effectiveness analysis involves assessment of each candidate system with respect to all effectiveness criteria over a range of conditions. These conditions may properly be called "parameters". They are the expected characteristics of spill incidents, the geographic and physical characteristics of spill sites, and the environmental conditions at spill sites. Records of spill sizes, frequencies, locations and environmental considerations were not available for this study. The parameters developed here are hypothetical and it is believed that they represent a realistic open sea situation for which the Navy remains responsible. Representative ranges for these aspects were derived from available historical information and descriptive materials. The parameters selected for this study, and the rationale for their development, are given in the following paragraphs.

#### Size of Spills

The size of spills from Navy AO and AOG ships can range from minor fuel handling incidents involving a few hundred gallons to a major incident where several compartments or a complete vessel is involved.

In the open sea, the major incident would be of most concern, the smaller spills being dispersed naturally in a few hours.

For purposes of this study, incidents were classified into three representative size ranges: 2700 gallons (10 tons), 270,000 gallons (1,000 tons), and 6,750,000 gallons (25,000 tons). These spills sizes represent: either (1) minor damage or personnel error, (2) the rupture of a large tank or several small tanks of an AO or AOG Naval vessel, or (3) the catastrophic loss of the total oil capacity of an AOR 1 Naval vessel.

#### Location of Spills

The proximity of a maritime casualty to valuable shore and near-shore resources can have considerable significance. The spreading and influence of wind and waves can put the oil onto a beach in a short time if the incident is close to land. The time available for spill cleanup is a direct function of the spill location and local hydrographic and meteorologic environment. Most spillage of significant size is a result of collision, groundings or adverse weather. The probability of each of these cases is enhanced the closer the vessel is to land. Two locations were chosen for use in this analysis: three miles from shore and twelve miles

from shore. Given the three sizes and two locations of spills, the following combinations are possible: (1) 2700 gallon spill 3 miles from shore, (2) 270,000 gallon spill 3 miles from shore, (3) 6,750,000 gallon spill 3 miles from shore, (4) 2700 gallon spill 12 miles from shore, (5) 270,000 gallon spill 12 miles from shore, and (6) 6,750,000 gallon spill 12 miles from shore. Midocean spills were not chosen for study cases because the spreading and dispersal of oil spills by wind and waves takes place so rapidly that by the time clean-up equipment would arrive at a mid-ocean spill, it would be impractical if not impossible to locate and treat the widely spread oil slicks.

## Frequency of Spillages

The frequency of spillage is important because of the effect of frequency upon system properties, i.e., maintenance, maneuverability and fixed versus variable costs. Clean-up costs per gallon of spillage will be quite high if a very few spills are encountered.

Spill frequencies of the incidents described previously can only be implied. The maritime casualty record of U.S. registered vessels worldwide and foreign vessels in U.S. waters will be used. The 1966 and 1967 reports are summarized below:(46)

Table 4. Casualty Records

| | FY 1966 | FY 1967 |
|---|---|---|
| Number of casualties, all types | 2,408 | 2,353 |
| Vessels over 1,000 tons* | 1,310 | 1,347 |
| Tank ships and tank barges* | 470 | 499 |
| Locations: | | |
| U. S. water | 1,685 | 1,569 |
| Elsewhere | 723 | 784 |
| Types of casualties: | | |
| Collision | 922 | 1,090 |
| Explosions | 175 | 168 |
| Grounding with damages | 302 | 282 |
| Floundering, capsizings, and floodings | 315 | 230 |

*Note that for the total number of vessels (1,846 in FY 1967) there were 2,353 casualties.

These data suggest that an order of magnitude of one casualty per vessel per year is experienced. If these were all oil carrying vessels, this would mean one spill per year. Considering the vessels involved, AO and AOG Naval vessels, and the spill sizes identified as important, 2700 gallons, 270,000 gallons, and 6,750,000 gallons, 25 percent of spills would be 270,000 gallons or greater (as from collisions) and 2.5 percent of spills would be 6,750,000 gallons or greater (as from groundings). Thus, with approximately forty AO and AOG vessels worldwide, ten 270,000 gallon spills and one 6,750,000 gallon spill might be expected per year, exclusive of war-time casualties. These estimates are based upon the types of casualties, their relative probability of occurring and upon the expectations of damage from these particular cases. It was assumed that the performance of U.S. Navy ships will be similar to commercial shipping. This is debatable because of superior Naval equipment, training and procedures in comparison to those typical of commercial shipping. Nevertheless, a frequency of spillage was required to assess costs and in the absence of specific Navy casualty data, that assumption was made. The number of minor, or 2700 gallon spills, is not estimated, there being no data on which to base an estimate. However, the frequency of the small spills has been considered in the cost analysis by varying the frequency to determine the effect.

Petroleum Products Spilled

This study is concerned with the petroleum products in use by the Navy:

JP-5 Turbine Fuel
Navy Special Fuel Oil
Bunker C Fuel Oil
Distillate Fuel

Specifications and characteristics of these materials are given elsewhere in this report.

## EFFECTIVENESS CRITERIA

The criteria for the effectiveness measurement should minimize the subjective judgment which must be employed. Rather than attempt to finely rank each system with respect to the criteria, which would inject undesirable subjective judgment into the analysis, we have chosen to establish the individual criteria in terms of minimal performance requirements. Each system is then given a numerical index which reflects whether it exceeds, meets, or fails to meet each of the criteria. The sum of these indices, for all combinations of parameters, then reflects the overall relative effectiveness of a particular system.

The effectiveness criteria employed in this study are listed in Table 5. The rationale for their development follows:

Table 5. Effectiveness Criteria

| Operational Aspect | Criteria |
| --- | --- |
| Completeness of Removal | Essentially complete removal in consideration of environmental, geographic, and hydrographic parameters. |
| Rate of Removal | Recovery at a rate such that removal from surface waters is complete before a slick contacts valued shore resources. Includes deployability and mobility considerations. |
| Does Not Increase Pollution or Hazard | Must not produce a situation having a higher pollution hazard or lower safety potential than the contaminating petroleum product alone. Primarily applicable to chemical or chemomechanical methods. |
| Applicability to Limited Access Areas | Must be capable of operation adjacent to ship salvage and shallow water areas which may limit access. Judgment based on maneuverability and size. |
| Sensitivity to Natural Phenomena or Floating Debris | Must be capable of operating under the anticipated sea, wind and current conditions prevailing at spill scenes 90% of the time. Must not be rendered inoperable by minor floating debris or, where applicable, by water-in-oil emulsions. |
| Toxicity to Marine Life | Will not contaminate fisheries and other commercially or recreationally significant marine life to cause mortality, condemnation of fish products, or flavor degradation. |
| Availability | Will be available for application at least 95% of the time in consideration of reliability, repairability, and level of skill required of candidate systems. |
| Sensitivity to Temperature | Must be capable of operating at temperatures of 40°F, i.e., must not be rendered inoperable by temperatures in the 40–50°F range. |

## Completeness of Oil Removal

One of the important performance characteristics of a petroleum product spill removal system is the degree to which it can approach complete removal of the petroleum product from the water surface. Systems which are less than perfect may be adequate if the fraction removed is sufficient to effectively mitigate the effects of the spill--property damage, destruction of marine life, and damage to recreational resources. This would be the case if the residual material remaining on the surface is harmlessly removed by natural mechanisms. Also, it requires that chemically dispersed or sunk materials do not reappear at the surface in sufficient quantities to become objectionable.

In reality, any system worthy of consideration must be theoretically capable of at least 90% complete removal of the spilled product from the water surface. Some systems, especially mechanical ones, cannot be expected to do this under adverse combinations of environmental, geographic, or hydrographic parameters considered in this study.

Each system was evaluated for the combinations of parameters involved in this study, by considering its design features which detract from or contribute to the completeness of petroleum product removal. Those which are capable of providing 90% or greater removal were given an index of (+2) and those which have severe limitations in this regard (less than 50%) were given an index of (0). Those which appear theoretically capable of 90% removal performance, but are undemonstrated for the particular combination of parameters involved, were given an index of (+1).

## Rate of Removal

A measure of the effectiveness of an oil spill countermeasure is its ability to contain or remove the spilled material before it damages vulnerable property or marine life. Removal must be effected before a slick becomes so thin that it is untreatable or unrecoverable.

Where the wind conditions are calm and currents are not significant, the rate of movement of the edge of a slick will be controlled by the spreading rate. No directly applicable quantitative data on spreading rates for the materials of concern (JP-5, Navy Special, Bunker C, and Distillate Fuel) have been found. However, the previously cited work of Blokker and Berridge, et al,[2,3] provides some basis for estimation of rates of oil slick spreading. Calculated slick characteristics based on these works are shown in Table 6. The Blokker equation can be stated as,

$$D^3 = \frac{24}{\pi} K(d_w - d_o) \frac{d_o}{d_w} V_o t + D_o^3$$

where $D$ = slick diameter, meters

$d_w, d_o$ = density of water and oil, respectively

$V_o$ = volume of oil, cubic meters

$t$ = time after spillage, minutes

$D_o$ = slick diameter at $t = 0$

$K$ = a constant depending on the oil.

Table 6. Theoretical Slick Dimensions After Spill

| | Time After Spill | 2,700 gal Spill Thickness (In. x $10^{-2}$) | 2,700 gal Spill Area (Ft.$^2$ x $10^6$) | 270,000 gal Spill Thickness (In. x $10^{-2}$) | 270,000 gal Spill Area (Ft.$^2$ x $10^6$) | 6,750,000 gal Spill Thickness (In. x $10^{-2}$) | 6,750,000 gal Spill Area (Ft.$^2$ x $10^6$) |
|---|---|---|---|---|---|---|---|
| JP-5 and Distillate Fuel | 1 Min. | 79 | .004 | 79 | 0.4 | 79 | 10.0 |
| | 10 Min. | 3.64 | .11 | 16.9 | 2.35 | 37.5 | 26.4 |
| | 1 Hr. | 1.01 | .394 | 4.8 | 8.24 | 13.4 | 73.9 |
| | 2 Hr. | .65 | .62 | 3.0 | 13.2 | 8.6 | 115.0 |
| | 5 Hr. | .35 | 1.14 | 1.63 | 24.3 | 4.72 | 210 |
| | 10 Hr. | .22 | 1.82 | 1.03 | 38.5 | 2.38 | 416 |
| Navy Special | 1 Min. | 79 | .004 | 79 | 0.4 | 79 | 10.0 |
| | 10 Min. | 6.15 | .065 | 28.7 | 1.38 | 51.5 | 19.2 |
| | 1 Hr. | 1.74 | .23 | 8.25 | 4.8 | 21.6 | 45.8 |
| | 2 Hr. | 1.09 | .366 | 5.18 | 7.65 | 14.3 | 69.4 |
| | 5 Hr | 0.60 | .668 | 2.79 | 14.2 | 7.92 | 125 |
| | 10 Hr. | 0.38 | 1.06 | 1.72 | 22.4 | 5.23 | 189 |
| Bunker C | 10 Hr. | 79 | .004 | 79 | 0.4 | 79 | 10.0 |

In these calculations, the density of sea water was assumed to be 1.02 $g/cm^3$ and the petroleum product density was taken from Table 1. The driving force for spreading is proportional to the difference in density between the water and oil and the instantaneous slick thickness. The density of Bunker C can be greater than that of sea water; therefore, Bunker C will have little tendency to spread. In addition, the pour point of Bunker C will usually be above the temperature of the sea water. This will further inhibit spreading.

Values of K for the petroleum products of interest in this study have not been determined. However, Blokker has determined this constant for several refined products, some of which resemble JP-5, Navy Special, and Distillate Fuel. The JP-5 and Distillate Fuel have similar densities and viscosities and closely correspond to Blokker's gas oil (Sp. Gr. = 0.83, $\mu$ = 4.3 cP at 20°C). Navy Special is similar to the lubricating oil tested in (Sp. Gr. = 0.90, $\mu$ = 490 cP at 20°C). The values of K, for these materials, were 15,000 $min^{-1}$ and 9,800 $min^{-1}$, respectively, and were used herein.

Spreading occurs in two phases. Blokker found that the first phase occurred rapidly until the slick thickness had reduced to about 2 cm and required about one minute for a 100 $m^3$ (26,400 gal.) spill. After the oil slick had reduced to this thickness, the Blokker spreading relationship would apply and the rate of spreading for JP-5, Distillate Fuel, or Navy Special can be estimated from the Blokker equation. Bunker C will not be expected to spread to less than 2 cm thickness.

According to Berridge, the thickness of a slick, after the lapse of a fully day, tends to approach the same value (0 0008 to 0.0012 in. in their reported tests) for a group of oils covering a wide range of properties. It is probable that the JP-5, Distillate Fuel, and Navy Special would all exhibit this characteristic.

At some point in time, the effects which compete with the spreading force will become controlling. These are evaporation with attendant density and viscosity changes, and the formation of water-in-oil emulsions. Evaporation, particularly, can become a very important factor for products having high vapor pressure constituents. Blokker found that up to 80% of a gasoline slick evaporated in three hours under moderate wind conditions. In the cases of interest in this study, evaporation is less important–but still causes the theoretical slick dimensions to be conservatively large.

The required recovery rate, within the previous context, revolves about the ability of a system to treat a given water surface area within a specified time span. Effectiveness criterion is best expressed for rapidly spreading materials as area treated per unit time. For slowly spreading materials such as Bunker C, the required recovery rate is best expressed as volume treated per unit time.

The material requiring most rapid treatment, on the basis of spread rates, is JP-5, followed by Distillate Fuel, Navy Special, and Bunker C, in that order. For Bunker C, where little or no spread tendency exists, the required treatment rate would be governed by other factors such as the need for operation during daylight hours or the need for recovery before winds or currents carry the material to shore.

For all treatment methods, deployment speed becomes an important consideration for rapidly spreading oil slicks.

For spills on the open sea, effective treatment could only be undertaken during daylight hours. For such cases, it is arbitrarily assumed that at least eight hours of daylight would be available for countermeasure activities in the vast majority of cases.

For some postulated spill cases, onshore currents and winds may become controlling.

It follows from the above discussion that different quantitative recovery rates are required for each combination of parameters For purposes of this study, and on the basis of the above reasoning, criteria were selected for various combinations of parameters. These are shown in Table 7.

It should be recognized that these detailed criteria apply to systems which do not utilize booms or other containment devices to prevent free wind-driven or spreading movement of the offending material.

For purposes of comparing various systems, the following indices were utilized in the total effectiveness:

| Rate of Removal | Index |
|---|---|
| System exceeds criteria | +2 |
| System meets criteria | +1 |
| Syste·· fails to meet criteria by 1 order of magnitude | 0 |
| System fails to meet criteria by 2 or more orders of magnitude | - 1 |

The purpose of the (-1) rating is to assist in identifying systems which may score well on other items but which, because of inability to effect cleanup within the required time span, could not be considered as practical systems.

Effect of Method on Pollution and Hazard

Generally, mechanical methods of spill treatment do not cause adverse effects. An exception to this would be mechanical systems which involve containment by booms or corrals when employed on spills of JP-5. Prevention of spreading of this flammable material, by gathering it in such containment, might be undesirable because of the associated fire hazard. Fire hazards may be minimized by the application of dispersants.

Chemical methods must be carefully considered because of the possibility that the chemical may be hazardous to personnel. Certain types of sorbents may create visibility hazards or ingestion hazards to personnel from dusty conditions. The possibility of dispersed or sunk materials reappearing at a later time must also be considered.

The indices applied were as follows:

| Effect | Index |
|---|---|
| Reduces Pollution or Hazard | +1 |
| No Effect on Pollution or Hazard | 0.5 |
| Increases Pollution or Hazard | 0 |

Applicability to Areas Having Limited Access

Many cases of oil spillage may result from the grounding of a vessel on a reef or protuberance. In these cases, rescue and recovery operations as well as oil spillage abatement procedures may be impaired. Shallow water areas may also influence the operation of certain mechanical devices. In the open sea environment, this effect will not be as pronounced as when near reef and shoaling areas. The Maritime Casualty Record reflects that many casualties are due to groundings. This was the case with the GENERAL

Table 7. Minimum Speed of Application Criterion for Governing Parameters

| Parameter: Location of Spill | Petroleum Product | Spill Size Gallons | Minimum Oil Treatment Rate | Basis |
|---|---|---|---|---|
| 1. Readily accessible open sea areas when environmental conditions are moderately severe; (assume wind 20 mph towards shore and spill 3 mi. offshore). | JP–5 and Distillate Fuel | 2,700 | 5,860 $Ft^2$/Min | Recovery or dispersing before oil reaches shore. One hour for deployment (equipment on the scene) and slick movement at 4% of wind velocity. |
| | | 270,000 | 124,000 $Ft^2$/Min | |
| | | 6,750,000 | 1,882,000 $Ft^2$/Min | |
| | Navy Special | 2,700 | 3,400 $Ft^2$/Min | |
| | | 270,000 | 75,800 $Ft^2$/Min | |
| | | 6,750,000 | 842,000 $Ft^2$/Min | |
| | Bunker C | 2,700 | 15 Gal/Min | |
| | | 270,000 | 1,540 Gal/Min | |
| | | 6,750,000 | 40,000 Gal/Min | |
| 2. Readily accessible open sea areas when environmental conditions are moderately severe; (assume wind 20 mph towards shore and spill 12 mi. offshore). | JP–5 and Distillate Fuel | 2,700 | 3,560 $Ft^2$/Min | Recovery or dispersing before oil reaches shore. Four hours for deployment (equipment on the scene) and slick movement at 4% of wind velocity assumed. |
| | | 270,000 | 82,300 $Ft^2$/Min | |
| | | 6,750,000 | 1,010,000 $Ft^2$/Min | |
| | Navy Special | 2,700 | 2,150 $Ft^2$/Min | |
| | | 270,000 | 47,500 $Ft^2$/Min | |
| | | 6,750,000 | 280,000 $Ft^2$/Min | |
| | Bunker C | 2,700 | 4 Gal/Min | |
| | | 270,000 | 380 Gal/Min | |
| | | 6,750,000 | 9,650 Gal/Min | |

COLOCOTRONIS, the TORREY CANYON, the OCEAN EAGLE, and the Tanker R.C. STONER. The R.C. STONER grounded near the harbor entrance to Wake Island, September 6, 1967.

Consideration of this aspect, in the effectiveness analysis, consists of evaluating each component of all hypothetical and actual systems in terms of:

- Access requirements in terms of water surface area and depth of planes perpendicular to water surface needed for effective mobility.
- Maneuverability of system in terms of turning radius and reversibility. Stability if floating or fixed objects are struck during movement.

Each system was individually evaluated for the parametric situations involving the characteristics mentioned above. Indices were assigned for each system as follows:

| Applicability to Limited Access Areas | Index |
|---|---|
| Exceeds Needs | +1.0 |
| Meets Needs | +0.5 |
| Does Not Meet Needs | 0 |

Sensitivity to Natural Phenomena or Floating Debris

Many mechanical systems are susceptible to stalling from pluggage or blockage by floating debris. It is usual for variable amounts of debris such as wood, paper, etc., to be present on the water surface after a major casualty. Those systems involving suction pumps, weirs, and close tolerance impellors are examples of systems which may be adversely affected by such materials. Design features such as screens, strainers, and baffles may enable a system to effectively handle such floating debris.

Systems employing rotating drums or endless belts of sorptive material are vulnerable to damage and stalling if rigid debris of irregular shape is picked up at the water surface. This characteristic may be contrary to some manufacturers' claims, but it has been observed during field application.

The sensitivity of a hypothetical or actual system to water wave and wind conditions is a significant performance factor. While it is unlikely that spillage cleanup would be of priority concern during severe storm conditions, effective systems must be usable during conditions more severe than "calm." It seems appropriate for purposes of this report to select conditions which would prevail during the vast majority of the time–applicable for as much as 90% of the time.

The section on reference environment and geography contains summary data on the geography and prevailing weather for selected areas frequented by U.S. Naval oilers and gasoline tankers. Appendix A includes wind distribution data. These data, along with calculated short period wave heights based on the method of Bretschneider[47], are given in Table A-4, Appendix A.

As can be seen from this table, the significant wave height for 90% probability varies from 1.0 to 13.0 ft. For the purpose of this study the significant wave height, world wide, during spill countermeasure operations will be taken as an average of these samplings which is 5.0 ft. By similar reasoning, the significant wind speed will be taken as 20 mph.

The indices applied to this aspect of countermeasure effectiveness are as follows:

| Effect | Index |
|---|---|
| Not affected by 5.0 ft. waves, 20 mph winds, or debris | +2 |
| Slightly affected by 5.0 ft. waves, 20 mph winds, or debris | 1.0 |
| Rendered inoperable by 5.0 ft. waves, 20 mph winds, or debris | 0 |

Toxicity to Marine Life

Most chemical dispersants are toxic to marine life. Toxicity thresholds range from approximately 5 ppm to 10,000 ppm for presently used commercial materials.[48] The actual effect of using a specific dispersant in a given situation is dependent on the marine life present, the diffusion characteristics at the spill locale, the effectiveness of tidal flushing, the application rate, and the physical characteristics of the spill material. Standards regulating the use of dispersants range from "unlimited" to "none permitted." FWQA rules employed during the Santa Barbara incident permitted chemical dispersants to be used at $>$ 1 mile off shore at concentrations equivalent to 5 ppm in the top three feet of water.[15] See Appendix F for FWQA recommendations for use of dispersants.

The FWQA rule of 5 ppm in the top three feet of water, although somewhat arbitrary, does have some logical basis. It assumes typical diffusion rates, is safely below the toxicity level for most dispersants, and assumes the dispersant is effectively mixed with the oil to provide some vertical distribution of the resulting oil-in-water emulsion. Use of this rule would permit chemical dispersant application at a rate of $9.5 \times 10^{-4}$ lb/ft$^2$ of surface area or 5 gallons per acre per 24 hours.

The amounts of chemicals required for emulsification is generally two to three times the manufacturer's recommendation–mostly due to the variance between field application and laboratory testing. A typical chemical dispersant must be used in the ratio 1:5 for effective use. This would correspond to effective treatments of oil slicks on the order of $5 \times 10^{-4}$ in. (or less) in thickness. Bunker C, because of its high density, would never be expected to spread this thinly. Navy Special as well as JP-5 and distillate fuel would not reduce to this thickness until a much later time than that necessary for removal (approximately 3 hours for a spill 3 miles from shore and 14 hours for a spill 12 miles from shore). It is concluded that chemical dispersants, within the above framework, cannot be effectively used within 1 mile of shore without exceeding most toxicity limits. In deep water, dispersants could be used more freely without known or measured adverse effects on marine life.

The indices applied to this criterion for system effectiveness evaluation were basically derived from the above reasoning. The applicability of chemical methods will depend on the circumstances of the specific spill situation and is exemplified as follows:

| Toxicity | Index |
|---|---|
| Systems allowing no toxic residuals | +2 |
| Systems or spill situations allowing residuals but not in excess of 5 ppm in top 3 ft. (when 1 mile or less from shore) or residuals $\geq$ 5 ppm in top 3 ft. but greater than 1 mile from shore | +1 |
| Systems or spill situations allowing residuals $\geq$ 5 ppm in top 3 ft. ($\leq$ 1 mile from shore) or affecting benthic organisms adversely | 0 |

### Availability

An effective system for removal of oil pollutants from the surfaces of open waters must, of necessity, be available for use when needed. Several factors influence the availability of specific systems:

- Reliability–invulnerability to failure due to malfunction or damage by external forces (such as waves, currents, and collisions).
- Maintainability–lack of dependence on special facilities or skills, ease of disassembly/assembly, and ready availability of replacement components.
- Portability–ability to quickly deploy to spill scene.

Many of the systems to be studied have been extensively used and corresponding historical data are available. Other systems have not been used enough to provide a sound basis for judging these aspects. In the latter instances, the systems were analyzed on the basis of the experience with components involved, or similar components, to derive estimates of availability probability.

| Availability | Index |
|---|---|
| Systems available $>$ 95% of the time | +2 |
| Systems available 50 95% of the time | +1 |
| Systems available $<$ 50% of the time | 0 |

### Sensitivity to Temperature

Systems for use in open sea conditions should be effective over the range of temperatures encountered in diverse geographic locations. Systems employing sorbents or suction devices may be expected to be adversely affected on thicker oils such as Navy Special and Bunker C at low temperatures. The action of chemical dispersants is also slowed by low temperatures. The mean sea surface temperature (Figure A-9, Appendix A) in most areas of potential spillage is between 40°F and 80°F, whereas the lowest mean sea temperature in the selected reference environments and geography is about 50°F. It is appropriate that the systems should be expected to function in temperatures down to at least 40°F. The indices applied for this criterion were derived from the above reasoning and are:

| Sensitivity to Temperature | Index |
|---|---|
| Not affected by temperatures of 40 50°F | +1 |
| Slightly affected by temperatures of 40 50°F | 0.5 |
| Rendered inoperable by temperatures of 40 50°F | 0 |

## POTENTIAL OIL TREATMENT AND/OR RECOVERY SYSTEM COMBINATIONS

The complexity of a recovery system varies greatly over the range of potential equipment, material and techniques. Three classifications of systems exist:

- Chemical
- Chemomechanical
- Mechanical

Chemical methods include those which treat the slick with chemical agents or materials and do not require subsequent mechanical recovery. Included within this classification are methods employing chemical dispersants, burning in situ, and enhanced degradation (biological or chemical).

Chemomechanical methods include those which employ both chemical and mechanical means of removal. Included within this classification are processes in which the oil is sorbed or gelled and subsequently retrieved by mechanical means, and sinking.

Mechanical recovery methods are those which employ only mechanical means to recover the product, such as skimmers, suction devices, and rotary drums or endless belts.

The delineation of total systems includes combinations of the general types of available equipment and materials within each classification. The potential systems identified within each classification were examined both with and without oil containment devices.

## Chemical Systems

a. Chemical dispersants applied directly to the slick with sufficient auxiliary agitation available.
b. System (a) + containment boom.
c. Chemical burning agents applied directly to the slick.
d. System (c) + containment boom.
e. Enhanced degradation (exclusive of chemical dispersants) by the addition of microorganisms, etc.

## Chemomechanical Systems

a. Sorbents/suction pump.
b. System (a) + containment boom.
c. Sorbents/conveyor.
d. System (c) + containment boom.
e. Gellants/conveyor.
f. System (e) + containment boom.
g. Sinking agents applied directly to the slick.
h. System (g) + containment boom.

## Mechanical Systems

a. Rotating drums.
b. System (a) + containment boom.
c. Endless belt.
d. System (c) + containment.
e. Suction devices.
f. System (e) + containment.
g. Advancing gravity skimmer or weir.
h. System (g) + containment boom.

## EFFECTIVENESS EVALUATION

The performance criteria and parameters which define the range of spill situations considered credible in this study have been combined to form a matrix, Figure 3, to enable a comparative effectiveness analyses of potential systems. Each worksheet (shown in Appendix E) refers to one postulated system; the sum of the index points for that system then is a comparative measure of the ability of that system to meet all of the criteria.

It must be pointed our that these systems are synthesized using state-of-the-art equipment, and are evaluated on known present capability.

The comparisons of all systems indicate that thirteen systems are superior (over 90 points). Of these, one (biological degradation) is judged impractical because of inability to meet requirements for rate of removal by several orders of magnitude. The potential systems in descending order of effectiveness are:

1. Chemical dispersants applied directly to the spill (229)
2. Chemical dispersants plus containment (151)
3. Advancing gravity skimmer or weir (133)
4. Gellants/conveyor (self-propelled) (132)
5. Gellants/conveyor plus containment (124)
6. Chemical burning agents applied directly to the spill (120)
*7. Enhanced degradation (addition of bacteria, enzymes, etc.) (120)
8. Chemical burning agents plus containment (114)
9. Advancing gravity skimmer or weir plus containment (109)
10. Sorbents/conveyor (self-propelled) (107)
11. Endless belt on water surface (portable) (106)
12. Sorbents/suction device plus containment (93)
13. Sorbents/conveyor plus containment (91)
14. Endless belt on water surface plus containment (87)
*15. Suction devices (portable) (87)
16. Sorbents/portable suction devices (83)
17. Sinking agents applied directly to slick (82)
18. Sinking agents plus containment (76)
*19. Rotating drums (self-propelled) (66)
*20. Rotating drums plus containment (66)
*21. Suction devices (portable) plus containment (63)

Containment generally does not improve the effectiveness of these systems. This is because [illegible] available booms are not reliable or effective for open water use. Dependence on a boom tends to make the system less effective, i.e., oil escapes and equipment to treat oil outside the boom is not available or planned for. The principal deficiency of most mechanical systems is inability to function effectively in 5-foot waves and 20 mph winds.

Certain controlling factors which can exist for individual spill incidents include: state or local pollution control regulations, port or harbor authority policy, the proximity of valuable shellfish or finfish areas, or recreation beaches. Any of these factors can eliminate an otherwise effective system from contention.

* These systems have 12 or more negative points (fails to meet rate of removal requirements by 2 orders of magnitude) indicating serious inability of available equipment or methods to meet rate of removal requirements. They are judged impractical to consider at the present time

Figure 3. Effectiveness Analysis Work Sheet

SYSTEM:

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

Criteria

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | | | | | | | | | |
| | | 2 | | | | | | | | | |
| | B | 1 | | | | | | | | | |
| | | 2 | | | | | | | | | |
| | C | 1 | | | | | | | | | |
| | | 2 | | | | | | | | | |
| | D | 1 | | | | | | | | | |
| | | 2 | | | | | | | | | |
| II | A | 1 | | | | | | | | | |
| | | 2 | | | | | | | | | |
| | B | 1 | | | | | | | | | |
| | | 2 | | | | | | | | | |
| | C | 1 | | | | | | | | | |
| | | 2 | | | | | | | | | |
| | D | 1 | | | | | | | | | |
| | | 2 | | | | | | | | | |
| III | A | 1 | | | | | | | | | |
| | | 2 | | | | | | | | | |
| | B | 1 | | | | | | | | | |
| | | 2 | | | | | | | | | |
| | C | 1 | | | | | | | | | |
| | | 2 | | | | | | | | | |
| | D | 1 | | | | | | | | | |
| | | 2 | | | | | | | | | |

TOTAL

It should also be recognized that in some cases the criteria can vary with the parameters, or parameters and criteria can be dependent on each other. An example of the variation with changing parameters is that much more relative speed is required for a large spill close to shore than for a small spill under similar conditions.

The parameters can also have different meanings depending on the type of system being considered. For a chemical system, wave action aids in dispersing to a point that the spilled material will not reappear and cause further pollution, while in a mechanical system the wave action is a hindrance.

Other notes of this type, developed during the effectiveness compilation, are given in the following paragraphs.

Completeness of Removal

Chemical Systems - Implies that the oil is essentially completely dispersed from the water surface and does not reappear at a later time. This means that where water-in-oil emulsions may form, as with Bunker C, or wave agitation is insufficient chemicals do not necessarily do a complete job, as they may reappear

Chemomechanical and Mechanical Systems - Implies that the system removes the oil from the water surface before it spreads or drifts out of range. Therefore, these systems must operate more rapidly on spills of lighter products. Also, the system must be capable of removing the oil accumulated around obstructions or booms. This is not the same as operating in limited access areas. For example, rotating drums have little or no ability to draw heavy or very light oils from the surrounding area and, therefore, will not do an essentially complete job. More importantly, the system must be capable of operating under the environmental conditions. Rotating drums and suction devices, for example, will be severely hampered by wave action in open sea conditions and the completeness of removal would be expected to be very low.

Rate of Removal

Speed often is an essential factor in completeness, i.e., the slick will spread too thin if it can't be recovered in time. A system which fails to function because the film thickness is too thin (as for burning where the film must be 0.03 inches thick or more) or which could not remove a slick before it reached the shore (as for enhanced biodegradation) would be severely penalized.

Hazard and Pollution

Includes water surface pollution to waterfowl, facilities and private boats (i.e., damage to recreation such as swimming), fire danger, air pollution, navigational danger and possible equipment damage from dusty conditions.

If a chemical dispersant reappears some time after treatment the pollution can be great. Sinking agents which release the oil at a later time are similarly ineffective.

System Use in Limited Access

Ability to maneuver, chase windrows of oil and work close to a ship. Also ability to pick up accumulated oil behind a containment boom and operability in shallow water for mechanical systems.

Sensitivity to Environmental Factors

Is the system itself sensitive to waves, etc., or does its capability for retrieval decrease? For this evaluation, it was considered that systems using containment booms available today would be penalized because the booms themselves would be subject to frequent overtoppings in 5 foot waves or could be expected to come apart or tip over. This has been the case to date with virtually every boom which has been subjected to open sea conditions. Model tests by Hydronautics Inc.[49] provide further evidence to support the ineffectiveness of booms in open sea conditions. The tests indicated that in sea state 5, which encompasses an average wave height of 5 to 7.9 ft, conventional booms would be overtopped frequently.

Toxicity

Applies only to chemicals. Excludes water fowl. The conclusions drawn in the report, the TORREY CANYON (Appendix B, Ref. 2) and others (Appendix B, Refs. 7 and 9), that the offshore spraying of detergents in deep water has no significant toxic or other deleterious effect on offshore or inshore fishing where applied to spills up to 270,000 gallons. However, for the 6,750,000 gallon spill, large amounts of dispersants would be required, much of which would likely be close to shore. For this case, the chances of exceeding 5 ppm near shore would be great.

Availability

Any self-propelled system must be penalized in this respect because the propulsion unit is bound to break down or require periodic maintenance. Portable gear is superior because it can use available vessels.

## E. COST ANALYSIS

### ASSUMPTIONS AND BASIC COSTS

The life cycle costs of the twelve systems which scored most effective over the full range of parameters were derived for the purpose of generating comparative cost effectiveness indices.

Systems that had severe limitations in accomplishing the oil removal or dispersal were not evaluated. Thus biological degrading was not evaluated because a spill would reach shore before any appreciable removal could be effected.

Several systems have common cost data, such as hourly labor charges. The hourly charge rates were derived from either commercial rental rates or the cost of new equipment

depreciated over its expected life. Some equipment charges such as booms were prorated per spill rather than on an hourly rate, based on procurement costs depreciated over the expected life. Maintenance costs were calculated on accepted chemical industry rates for equipment in moderate to severe corrosive environment (10% of acquisition cost/year for mechanical equipment, 5% of acquisition cost/year for booms).

Assumed equipment costs, labor and material costs common to several or all systems include:

1. Personnel Hourly Rate — $10/man hour

This is a conservative estimate of the cost per man-hour based on an eight hour day and including overhead and fringe benefits.

2. Containment Booms — $20/ft or $60,000/system

Based on a length of 3000 feet, considered likely the maximum length which can be deployed and maneuvered for encircling a ship or spill. The boom must be capable of being deployed rapidly from a workboat to enable placement in 30 minutes after arrival on the scene. Deployment costs per incident, including set up, positioning, recovery and cleanup are estimated at 16 manhours plus four hours of intermediate boat time and $40 of miscellaneous materials for cleanup, etc. The total cost per incident is then $320. A useful boom life of two years was used.

3. Disposal — $0.50/gal

The 0.50/gallon represents the cost of transporting, transferring and cleanup of transfer vessels for disposal, either at a storage location, processing for use as a fuel for power plants, or landfill.

4. Auxiliary Surface Craft — Intermediate $30/Hr (with crew)<br>Large $40/Hr (with crew)

Two sizes of surface craft were selected for the different systems. The large size craft (40-80 ft) are suitable for application of dispersants and have the capability for carrying decanting or separation tanks for recovered oil-water mixtures or towing barges for storage of recovered sorbent and oil, etc. The cost of this type of craft is assumed to be $40/hr. including crew. The intermediate craft, up to 30 ft. are suitable for mixer applications on dispersants and sorbents and can also be used for deployment and positioning of booms. The cost of this type of craft is assumed to be $30/hr., including crew.

5. Burning Agents — Glass beads - See below<br>Silicon dioxide $0.016/gal.

Two type of burning agents have been demonstrated in sea trials to be able to burn Bunker C. They are a cellated glass beads and a silicon doxide powder. Burning agents will function only on fairly thick slicks and in general must be confined to contained slicks or uncontained Bunker C which does not spread to below the critical thicknesses. For glass beads the minimum film thickness is .03" and the slick can be completely burned under the proper conditions. The application required is .10 lbs/ft $^2$ regardless of film thickness and the cost is $0.90/lb. Costs for various spill sizes using glass beads are:

| | |
|---|---|
| 2,700 gallon spill - Navy Special Not contained | \$4.32/Gal. |
| 270,000 gallon spill - Navy Special Not contained | \$432/Gal. |
| All sizes Bunker C - Not contained (0.79" thick) | \$0.15/Gal. |
| All sizes Bunker C and Navy Special/contained, 3" thick | \$.048/Gal. |

These costs were applied to the individual situations, considering only Bunker C for uncontained spills and only Navy Special and Bunker C for contained spills. The 2,700 gallon Navy Special spill requires application of glass beads within 10 minutes after the spill before it reaches the critical thickness (.03"). The 270,000 gallon Navy Special spill requires 1,170,000 lbs. of the beads at its critical thickness reached about two hours after the spill. The silicon dixide powder is applied at 1/10% of the weight of oil on slicks .06" or thicker. The cost per pound is \$1.95. The cost per gallon of oil burned is then \$0.016. This cost was applied the same as stated above for glass beads.

| | | | |
|---|---|---|---|
| 6. | Sorbents | Commercial bulk materials (non foam) | 0.30 Gal. |
| | | Polymer foams | 0.10/Gal. |
| | | Straw | 0.03/Gal. |

Three general types of sorbents are considered: (1) commercial bulk material such as perlite, vermiculite, talc, shredded bark; (2) polymer foams such as polyurethane, polypropylene and polyethylene; and (3) straw. Commercial sorbents typically cost \$100 to \$250/ton and will absorb 3 or more times their weight in oil. cost per gallon treated would be \$0.30. Soft polymer foams have potential if efficient spreading and recovery systems become available. Oil can be recovered from some of these products. Polyurethane foam costs approximately \$0.50/lb. and one pound will absorb about 5 gallons under field conditions; thus, the cost is about \$0.10/gallon. Straw is almost universally available (reportedly not available in Hawaii) and will absorb about five times its weight in oil. The cost of straw is about \$30/ton making the cost per gallon about \$0.03.

7. Gelling Agents — \$3.00/Gal.

At least one gelling agent is commercially available ("Spill-Away" manufactured by Amerace-ESNA Corp.). It can be sprayed, is relatively non-toxic to marine life and costs approximately \$3.00/gal. The application rate ranges from about 1:3 to 1:1. A conservative value of 1:1 was assumed for all products, making the cost \$3.00/gallon of gelled oil.

8. Chemical Dispersants — \$0.60/Gal.

There are many dispersant products which may be used to treat oil spills, ranging in price from about \$1.80 to \$5.00/gallon. Application ratios vary and are dependent on several factors, but effective application rates are generally about 1 part dispersant to 5 parts oil. Assuming an average of \$3/gal. and 5 parts of oil dispersed per gallon, the cost of oil dispersed is about \$0.60/gal. Other costs, such as labor, pumps and spray equipment are added in the individual incidents as they are with other systems.

The spill situations previously described are designated as Situation I (2700 gallon spill), Situation II (270,000 gallon spill), and Situation III (6,750,000 gallon spill). The frequency of Situation I was varied for 10, 50 and 100 incidents per year to determine the effect on the cost. Situation II was determined for 10 incidents per year and Situation III considered one spill per year. The purpose of varying Situation I was to assist in determination of the most effective system for different frequencies of small spills since this frequency is unknown.

## COST COMPILATION

### 1. Chemical Dispersants Applied Directly to the Spill

Situation I: 2,700 gal Spill

Variable Costs:

| | | |
|---|---|---|
| Chemical dispersants: | | |
| (2,700 gal) ($0.60/gal) | $ | 1,620 |
| Labor: (8 man-hr) | | 80 |
| Surface craft: | | |
| One large craft 4 hr @ $40/hr | | 160 |
| Two intermediate 8 hr @ $30/hr | | 240 |
| | $ | 2,100 |

Fixed Costs:

| | | |
|---|---|---|
| Capital costs/yr (pumps and spray equip) | | |
| $8,600/5 yr | | 1,720 |
| Maintenance costs/yr | | 860 |
| Storage costs/yr | | 550 |
| | $ | 2,130 |

Cost/incident for 50 incidents – $2,142

| Cost/gal. for | |
|---|---|
| 10 incidents | $0.86 |
| 50 incidents | $0.80 |
| 100 incidents | $0.79 |

Situation II. 270,000 gal Spill

Variable Costs:

| | | |
|---|---|---|
| Chemical Dispersants: | | |
| (270,000 gal) ($0.60/gal) | | 162,000 |
| Labor: (32 man-hr) | | 320 |
| Surface craft: | | |
| Four large craft 16 hr @ $40/hr | | 640 |
| Eight intermediate 32 hr @ $30/hr | | 960 |
| | $ | 163,920 |

Fixed Costs:

| | | |
|---|---|---|
| Capital costs/yr (pumps and spray equip) | | |
| $8,600/vessel/5 yrs | $ | 6,880 |
| Maintenance costs/yr | | 3,440 |
| Storage costs/yr | | 1,650 |
| | $ | 11,970 |

Cost/incident for 10 incidents - $165,117
Cost/gal for 10 incidents - $0.61

Situation III: 6,750,000 gal Spill

Variable Costs:

| | |
|---|---|
| Chemical Dispersants: | |
| ($6.75 \times 10^6$ gal) ($0.60/gal) | 4,050,000 |
| Labor: (1,200 man-hr) | 12,000 |
| Surface craft: | |
| Four large craft 400 hr @ $40/hr | 16,000 |
| Eight intermediate 800 hr @ $30/hr | 24,000 |
| | $4,102,000 |

Fixed Costs:

| | | |
|---|---|---|
| Capital costs/hr (pumps and spray equip) | | |
| $8,600/vessel/5 yr | | 6,880 |
| Maintenance costs/yr | | 3,440 |
| Storage costs/yr | | 1,650 |
| | $ | 11,970 |

Cost/incident $4,113,970
Cost/gallon – one incident – $0.61

2. Chemical Dispersants Plus Containment Boom

Situation I: 2,700 gal Spill

Variable Costs:

| | | |
|---|---|---|
| As estimated for dispersants alone | | 2,100 |
| Place and clean boom | | 320 |
| | $ | 2,420 |

Fixed Costs:

| | |
|---|---|
| As estimated for dispersants alone | $ 2,130 |
| Capital costs/yr, boom, $60,000/2 yr | 30,000 |
| Maintenance costs/yr, boom | 3,000 |
| | $ 35,130 |

Cost/incident for 50 incidents - $3,125

Cost/gal for

| | |
|---|---|
| 10 incidents | $2.19 |
| 50 incidents | $1.16 |
| 100 incidents | $1.02 |

Situation II: 270,000 gal Spill

Variable Costs:

| | |
|---|---|
| As estimated for dispersants alone | 163,920 |
| Place and clean boom | 320 |
| | $ 164,240 |

Fixed Costs:

| | |
|---|---|
| As estimated for dispersants alone | 11,970 |
| Capital costs/yr, boom, $60,000/2 yr | 30,000 |
| Maintenance costs/yr, boom | 3,000 |
| | $ 44,970 |

Cost/incident for 10 incidents - $168,737
Cost/gal for 10 incidents - $0.62

Situation III: 6,750,000 gal Spill

Variable Costs:

| | |
|---|---|
| As estimated for dispersants alone | 4,102,000 |
| Place and clean boom | 320 |
| | $4,102,320 |

Fixed Costs:

| | |
|---|---|
| As estimated for dispersants alone | 11,970 |
| Capital costs/yr, boom, $60,000/2 yr | 30,000 |
| Maintenance costs/yr, boom | 3,000 |
| | $ 44,970 |

Cost/incident - $4,147,290
Cost/gallon - one incident - $0.61

3. Advancing Skimmer

The cost of an advancing skimmer similar to that used by Union Oil Company at Santa Barbara is estimated at $50,000 for the skimmers (one each side of a large craft), pumps and on-board storage/decanting tanks. The capacity is taken at 2,000 gal/day per craft.

Situation I: 2,700 gal Spill

Variable Costs:

| | |
|---|---|
| Labor: (15 man-hr) | $ 150 |
| Surface craft: | |
| One large craft 5 hr @ $40/hr | 200 |
| Disposal: (2,700 gal) ($0.50/gal) | 1,350 |
| | $ 1,700 |

Fixed Costs:

| | |
|---|---|
| Capital costs/yr, skimmer, pumps, tanks, $50,000/4 yrs | 12,500 |
| Maintenance costs/yr | 5,000 |
| Storage costs/yr | 550 |
| | $ 18,050 |

Cost/incident for 50 incidents - $2,061

Cost/gal for

| | |
|---|---|
| 10 incidents | $1.30 |
| 50 incidents | $0.77 |
| 100 incidents | $0.70 |

Situation II: 270,000 gal Spill

Variable Costs:

| | |
|---|---|
| Labor: (700 man-hr) | 7,000 |
| Surface Craft: | |
| Four large craft 280 hr @ $40/hr | 11,200 |
| Disposal: (270,000 gal) (0.50 gal) | 135,000 |
| | $ 153,200 |

**Fixed Costs:**

| | |
|---|---|
| Capital costs/yr, $200,000/4 yrs | $ 50,000 |
| Maintenance costs/yr | 20,000 |
| Storage costs/yr | 2,000 |
| | $ 72,000 |

Cost/incident for 10 incidents - $160,400
Cost/gal for 10 incidents - $0.60

Situation III: 6,750,000 gal Spill

**Variable Costs:**

| | |
|---|---|
| Labor (14,000 man-hr) | 140,000 |
| Surface craft:<br>Four large craft 6240 hr @ $40/hr | 249,600 |
| Disposal: (6.75 x $10^6$ gal) (0.50/gal) | 3,375,000 |
| | $3,764,600 |

**Fixed Costs:**

| | |
|---|---|
| Same as Situation II | $ 72,000 |

Cost/incident - $3,836,000
Cost/gal - one incident - $0.57

4. Gellants/Conveyor

Situation I: 2,700 gal Spill

**Variable Costs:**

| | |
|---|---|
| Gellants:<br>(2,700 gal) ($3.00/gal) | 8,100 |
| Labor: (25 man-hr) | 250 |
| Surface craft:<br>One large craft 4 hr @ $40/hr | 160 |
| Disposal: (2,700 gal) ($0.50/gal) | 1,350 |
| | $ 9,860 |

Fixed Costs:

| | | |
|---|---|---|
| Capital costs/yr, mechanical recovery equipment, \$50,000/4 yr | \$ | 12,500 |
| Maintenance cost/yr | | 5,000 |
| Storage costs/yr | | 550 |
| | \$ | 18,050 |

Cost/incident for 50 incidents - \$10,220

Cost/gal for

10 incidents - \$4.30

50 incidents - \$3.79

100 incidents - \$3.72

Situation II: 270,000 gal Spill

Variable Costs:

| | |
|---|---|
| Gellants: (270,000 gal) (3.00/gal) | 810,000 |
| Labor: (732 man-hr) | 7,320 |
| Surface craft: Four large craft - 16 hr @ \$40/hr | 640 |
| Disposal: (270,000 gal) (\$0.50 gal) | 135,000 |
| | \$ 952,960 |

Fixed Costs:

| | |
|---|---|
| Capital costs/yr, mechanical recovery equipment 200,000/4 yr | 50,000 |
| Maintenance costs/yr | 20,000 |
| Storage costs/yr | 2,000 |
| | \$ 72,000 |

Cost/incident for 10 incidents - \$960,160

Cost/gal for 10 incidents - \$3.56

Situation III: 6,750,000 gal Spill

Variable Costs:

| | |
|---|---|
| Gellants: ($6.75 \times 10^6$ gal) (\$3.00/gal) | 20,250,000 |
| Labor: (15,200 man-hr) | 152,000 |

| | |
|---|---|
| Surface craft: | |
| Four large craft 400 hr @ $40/hr | $ 16,000 |
| Disposal: (6.75 x $10^6$ gal) ($0.50/gal) | 3,375,000 |
| | $23,793,000 |

Fixed Costs:

| | |
|---|---|
| Capital costs/yr, mechanical recovery equipment, $200,000/4 yr | 50,000 |
| Maintenance costs/yr | 20,000 |
| Storage costs/yr | 2,000 |
| | $ 72,000 |

Cost/incident - $23,865,000
Cost/gal - 1 incident - $3.54

5. Gellants/Conveyor Plus Containment Boom

Situation I: 2,700 gal Spill

Variable Costs:

| | |
|---|---|
| As estimated for gellants/conveyor | 9,860 |
| Place and clean boom | 320 |
| | $ 10,180 |

Fixed Costs:

| | |
|---|---|
| As estimated for gellants/conveyor | 18,050 |
| Capital costs/yr, boom, $60,000/2 yr | 30,000 |
| Maintenance costs/yr, boom | 3,000 |
| | $ 51,050 |

Cost/incident for 50 incidents - $11,200
Cost/gal for
10 incidents - $5.65
50 incidents - $4.15
100 incidents - $3.96

Situation II: 270,000 gal Spill

Variable Costs:

| | |
|---|---|
| As estimated for gellants/conveyor | 952,960 |
| Place and clean boom | 320 |
| | $ 953,280 |

Fixed Costs:

| | | |
|---|---|---|
| As estimated for gellants/conveyor | $ | 72,000 |
| Capital costs/yr, boom, $60,000/2 yr | | 30,000 |
| Maintenance costs/yr, boom | | 3,000 |
| | $ | 105,000 |

Cost/incident for 10 incidents - $963,780
Cost/gal for 10 incidents - $3.57

Situation III: 6,750,000 gal Spill

Variable Costs:

| | |
|---|---|
| As estimated for gellants/conveyor | 23,793,000 |
| Place and clean boom | 320 |
| | $23,793,320 |

Fixed Costs:

| | | |
|---|---|---|
| As estimated for gellants/conveyor | | 72,000 |
| Capital costs/yr, boom $60,000/2 yr | | 30,000 |
| Maintenance costs/yr, boom | | 3,000 |
| | $ | 105,000 |

Cost/incident - $23,898,320
Cost/gal - one incident - $3.55

6. Chemical Burning Agents Applied Directly to the Spill

Costs for two types of burning agents (cellated glass beads and silicon dioxide powder) are considered because the cost/gallon of oil treated varies considerably between these agents. For the cellated glass bead type, the cost is dependent on the area of the spill whereas for silicon dioxide, the cost is dependent on the amount of oil. For the uncontained spill, the cost per gallon is applied only to Bunker C since it is the only product which, under normal circumstances, will be thick enough to burn when spill treating equipment arrives.

6a. Cellated Glass Bead Type

Situation I: 2,400 gal Spill Bunker C

Variable Costs:

| | |
|---|---|
| Burning agent: (400 lbs)<br>(2,400 gal) ($0.15/gal) | 360 |

| | | |
|---|---|---|
| Labor: (8 man-hr) | $ | 80 |
| Surface craft: | | |
| One large craft 4 hr @ $40/hr | | 160 |
| | $ | 600 |

Fixed Costs:

| | | |
|---|---|---|
| Capital costs/yr. spreader, $2,000/3 yr | | 667 |
| Maintenance costs/yr | | 200 |
| Storage costs/yr | | 13 |
| | $ | 880 |

Cost/incident for 50 incidents - $618
Cost/gal for
10 incidents - $0.29
50 incidents - $0.26
100 incidents - $0.25

Situation II: 240,000 gal Spill Bunker C

Variable Costs:

| | | |
|---|---|---|
| Burning agent: (40,000 lbs) (240,000 gal) ($0.15/gal) | | 36,000 |
| Labor: (40 man-hr) | | 400 |
| Surface craft: | | |
| Four large craft - 16 hr @ $40/hr | | 640 |
| | $ | 37,040 |

Fixed Costs:

| | | |
|---|---|---|
| Capital costs/yr 8 spreaders, $16,000/3 yr | | 5,340 |
| Maintenance costs/yr, spreaders | | 1,600 |
| Storage costs/yr | | 100 |
| | $ | 7,040 |

Cost/incident for 10 incidents - $37,774
Cost/gal for 10 incidents - $0.16

Situation III: 6,000,000 gal Spill Bunker C

Variable Costs:

| | | |
|---|---|---|
| Burning agent: (1,000,000 lbs) ($6.0 \times 10^6$ gal) ($0.15/gal) | | 900,000 |

| | |
|---|---|
| Labor: (9,600 man-hr) | $ 96,000 |
| Surface craft: | |
| Four large craft 1,200 hr @ $40/hr | 48,000 |
| | $ 1,044,000 |

Fixed Costs:

| | |
|---|---|
| Same as for Situation II | 7,040 |

Cost/incident - $1,051,040
Cost/gal - One incident - $0.18

6b. Silicon Dioxide Powder Type

Situation I: 2,400 gal Spill Bunker C

Variable Costs:

| | |
|---|---|
| Burning agent: (20 lbs) (2,400 gal) ($0.016/gal) | 40 |
| Labor: (8 man-hr) | 80 |
| Surface craft: One large craft 4 hr @ $40/hr | 160 |
| | $ 280 |

Fixed Costs:

| | |
|---|---|
| Capital costs/yr, spreader, $2,000/3 yr | 667 |
| Maintenance costs/yr | 200 |
| Storage costs/yr | 13 |
| | $ 880 |

Cost/incident for 50 incidents - $298
Cost/gal for
10 incidents - $0.15
50 incidents - $0.13
100 incidents - $0.12

Situation II: 240,000 gal Spill Bunker C

Variable Costs:

| | |
|---|---|
| Burning agent: (2,000 lbs) (240,000 gal) ($0.016/gal) | 4,000 |

| | | |
|---|---|---|
| Labor: (16 man-hr) | $ | 160 |
| Surface craft: | | |
| One large craft - 8 hr @ $40/hr | | 320 |
| | $ | 4,480 |

Fixed Costs:

| | | |
|---|---|---|
| Capital costs/yr, 2 spreaders, $4,000/3 yr | | 1,660 |
| Maintenance costs/yr, spreaders | | 400 |
| Storage costs/yr | | 40 |
| | $ | 2,100 |

Cost/incident for 10 incidents - $4,690
Cost/gal for 10 incidents - $0.02

Situation III: 6,000,000 gal Spill Bunker C

Variable Costs:

| | | |
|---|---|---|
| Burning agent: (50,000 lbs) | | |
| ($6.0 \times 10^6$ gal) ($0.016/gal) | | 96,000 |
| Labor: (96 man-hr) | | 960 |
| Surface craft: | | |
| Four large craft 40 hr @ $40/hr | | 1,600 |
| | $ | 98,560 |

Fixed Costs:

| | | |
|---|---|---|
| Capital costs/yr, 8 spreaders, $16,000/3 yr | | 5,340 |
| Maintenance costs/yr, spreaders | | 1,600 |
| Storage costs/yr | | 100 |
| | $ | 7,040 |

Cost/incident - $105,600
Cost/gal - One incident - $0.02

7. Chemical Burning Agents with Containment Boom

As in the previous cost compilation, two burning agents are considered. The cost of a fireproof boom is estimated at $25/ft or $75,000 for a 3,000 foot boom. Contained Navy Special and Bunker C are considered and a nominal thickness of 3 inches is assumed for these products.

7a. Cellated Glass Bead Type

Situation I: 2,700 gal Spill (Navy Special or Bunker C)

Variable Costs:

| | | |
|---|---|---|
| Burning agent: (150 lbs) (2,700 gal) ($0.048/gal) | $ | 130 |
| Labor: (8 man-hr) | | 80 |
| Surface craft: One large craft 4 hr @ $40/hr | | 160 |
| Place and clean boom | | 320 |
| | $ | 690 |

Fixed Costs:

| | | |
|---|---|---|
| Capital costs/yr: | | |
| Spreader, $2,000/3 yr | | 667 |
| Fireproof boom, 75,000/3 yr | | 37,500 |
| Maintenance costs/yr | | 3,800 |
| Storage costs/yr | | 33 |
| | $ | 42,000 |

Cost/incident for 50 incidents - $1,530
Cost/gal for:
10 incidents - $1,80
50 incidents - $0.57
100 incidents - $0.41

Situation II: 270,000 gal Spill (Navy Special or Bunker C)

Variable Costs:

| | | |
|---|---|---|
| Burning agent: (14,400 lbs) (270,000 gal) ($0.048/gal) | | 13,000 |
| Labor: (40 man-hr) | | 400 |
| Surface craft: two large craft - 8 hr @ $40/hr | | 320 |
| Place and clean boom | | 320 |
| | $ | 14,040 |

Fixed Costs:

| | | |
|---|---|---|
| Capital costs/yr: | | |
| Two spreaders, $4,000/3 yr | $ | 1,667 |
| Fireproof boom, $75,000/2 yrs | | 37,500 |
| Maintenance costs/yr | | 4,150 |
| Storage costs/yr | | 33 |
| | $ | 43,350 |

Cost/incident for 10 incidents - $18,375
Cost/gal for 10 incidents - $0.07

Situation III: 6,750,000 gal Spill (Navy Special or Bunker C)

Variable Costs:

| | |
|---|---|
| Burning agent: (360,000 lbs) (6.75 x $10^6$ gal) ($0.048/gal) | 324,000 |
| Labor: (9,600 man-hr) | 96,000 |
| Surface craft: Four large craft 1,200 hr @ $40/hr | 48,000 |
| Place and clean boom (5 times) | 1,600 |
| | $ 469,600 |

Fixed Costs:

| | |
|---|---|
| Capital costs/yr: | |
| 8 spreaders, $16,000/3 yr | 5,340 |
| Fireproof boom, $75,000/2 yr | 37,500 |
| Maintenance costs/yr | 4,600 |
| Storage costs/yr | 100 |
| | $ 47,540 |

Cost/incident - $517,140
Cost/gal - one incident - $0.08

7b. Silicon Dioxide Powder Type

Situation I: 2,700 gal Spill (Navy Special or Bunker C)

Variable Costs:

| | |
|---|---|
| Burning agent: (20 lbs) (2,700 gal) ($0.016/gal) | 40 |

| | | |
|---|---|---|
| Labor: (8 man-hr) | $ | 80 |
| Surface craft: | | |
| One large craft 4 hr @ $40/hr | | 160 |
| Place and clean boom | | 320 |
| | $ | 600 |

Fixed Costs:

| | |
|---|---|
| Same as cellated glass bead type | 42,000 |

Cost/incident for 50 incidents - $1,440
Cost/gal for
10 incidents - $1.78
50 incidents - $0.53
100 incidents - $0.38

Situation II: 270,000 gal Spill (Navy Special or Bunker C)

Variable Costs:

| | | |
|---|---|---|
| Burning agent (2,000 lbs) (270,000 gal) ($0.016/gal) | | 4,000 |
| Labor: (16 man-hr) | | 160 |
| Surface craft: | | |
| One large craft - 8 hr @ $40/hr | | 320 |
| Place and clean boom | | 320 |
| | $ | 4,800 |

Fixed Costs:

| | |
|---|---|
| Same as cellated glass beads type | 43,350 |

Cost/incident for 10 incidents - $9,135
Cost/gal for 10 incidents - $0.04

Situation III: 6,750,000 gal Spill (Navy Special or Bunker C)

Variable Costs:

| | | |
|---|---|---|
| Burning agent: (50,000 lbs) ($6.75 \times 10^6$ gal) ($0.016/gal) | $ | 108,000 |

| | | |
|---|---|---|
| Labor: (96 man-hr) | $ | 960 |
| Surface craft: | | |
| Four large craft 40 hr @ $40/hr | | 1,600 |
| Place and clean boom (5 times) | | 1,600 |
| | $ | 112,160 |

Fixed Costs:

| | | |
|---|---|---|
| Same as cellated glass beads type | $ | 47,540 |

Cost/incident -$159,700
Cost/gal - one incident - $0.03

8. Advancing Skimmer with Containment Boom

The same assumptions made for the advancing skimmer equipment without containment (Item 4) are used here.

Situation I: 2,700 gal Spill

Variable Costs:

| | | |
|---|---|---|
| Labor: (10 man-hr) | | 100 |
| Surface craft: | | |
| One large craft 3 hr @ $40/hr | | 120 |
| Disposal (2,700 gal) ($0.50/gal) | | 1,350 |
| | $ | 1,570 |

Fixed Costs:

| | | |
|---|---|---|
| Capital costs/yr: | | |
| Skimmer, $50,000/4 yr | | 12,500 |
| Boom, $60,000/2 yr | | 30,000 |
| Maintenance costs/yr, skimmer, boom | | 8,000 |
| Storage costs/yr | | 550 |
| | $ | 51,050 |

Cost/incident for 50 incidents - $2,590
Cost/gal for
10 incidents - $2.48
50 incidents - $0.96
100 incidents - $0.77

Situation II: 270,000 gal Spill

Variable Costs:

| | |
|---|---|
| Labor: (400 man hr) | $ 4,000 |
| Surface craft: | |
| Four large craft - 160 hr @ $40/hr | 6,400 |
| Disposal (270,000 gal) (0.50 gal) | 135,000 |
| Place and clean boom | 320 |
| | $ 145,720 |

Fixed Costs:

| | |
|---|---|
| Capital costs/yr: | |
| Four skimmers, $200,000/4 yr | 50,000 |
| Boom, $60,000/2 yr | 30,000 |
| Maintenance costs/yr | 23,000 |
| Storage costs/yr | 2,000 |
| | $ 105,000 |

Cost/incident for 10 incidents - $156,220
Cost/gal for 10 incidents - $0.58

Situation III: 6,750,000 gal Spill

Variable Costs:

| | |
|---|---|
| Labor: (8,000 man-hr) | 80,000 |
| Surface craft: | |
| Four large craft 3,400 hr @ $40/hr | 136,000 |
| Disposal: $(6.75 \times 10^6$ gal) ($0.50/gal) | 3,375,000 |
| Place and clean boom | 320 |
| | $ 3,591,320 |

Fixed Costs:

| | |
|---|---|
| Same as Situation II | $ 105,000 |

Cost/incident - $3,696,320
Cost/gal - one incident - $0.55

9. **Sorbents/Conveyor**

A mechanical conveyor specifically designed for recovery of an agglomerated mixture of oil and sorbents or gelled petroleum products is not presently available. Devices intended for aquatic weed or kelp harvesting could be adapted for recovery of these mixtures. The cost of these units and associated spreader is estimated to be $50,000 and the estimated useful life is four years.

Situation I: 2,700 gal Spill

**Variable Costs:**

| | | |
|---|---|---|
| Sorbents (Assume $0.10 gal as average of sorbents) (2,700 gal) ($0.10/gal) | $ | 270 |
| Labor: (35 man-hr) | | 350 |
| Surface craft: One large craft 4 hr @ $40/hr | | 160 |
| Disposal (2,700 gal) ($0.50/gal) | | 1,350 |
| | $ | 2,130 |

**Fixed Costs:**

| | | |
|---|---|---|
| Capital costs/yr, mechanical recovery equipment and spreader, $50,000/4 yr | | 12,500 |
| Maintenance costs/yr | | 5,000 |
| Storage costs/yr | | 550 |
| | $ | 18,050 |

Cost/Incident for 50 Incidents - $2,491
Cost/gal for
10 Incidents - $1.46
50 Incidents - $0.93
100 Incidents - $0.86

Situation II: 270,000 gal Spill

**Variable Costs:**

| | |
|---|---|
| Sorbents: (270,000 gal) ($0.10/gal) | 27,000 |
| Labor: (800 man-hr) | 8,000 |
| Surface craft: Four large craft - 16 hr. @ $40/hr | 640 |

| | |
|---|---|
| Disposal: (270,000 gal) (0.50/gal) | $ 135,000 |
| | $ 170,640 |

Fixed Costs:

| | |
|---|---|
| Capital costs/yr | |
| Spreaders and mechanical recovery equipment, $200,000/4 yr | 50,000 |
| Maintenance costs/yr | 20,000 |
| Storage costs/yr | 2,000 |
| | $ 72,000 |

Cost/incident for 10 incidents - $177,840
Cost/gal for 10 incidents - $0.66

Situation III: 6,750,000 gal Spill

Variable Costs:

| | |
|---|---|
| Sorbents: $(6.75 \times 10^6$ gal) ($0.10/gal) | 675,000 |
| Labor: (17,000 man-hr) | 170,000 |
| Surface craft: Four large craft 400 hr @ $40/hr | 16,000 |
| Disposal: $(6.75 \times 10^6$ gal) ($0.50/gal) | 3,375,000 |
| | $ 4,236,000 |

Fixed Costs:

| | |
|---|---|
| Same as Situation II | 72,000 |

Cost/incident - $4,308,000
Cost/gal - one incident - $0.64

10. Endless Belt on Water Surface

Numerous endless belt type skimmers are available most of which are suitable only for harbor use. One device (the "Oilevator") is available which is said to remove 40 gpm of Bunker C, crude oil, diesel oil and lubricating oil in a two foot swell condition and to withstand 5 foot waves and a 20 mph wind. The unit can be barge mounted. The cost of these units is $7,500 each and the cost of barges is assumed to be $20/hr.

Situation I: 2,700 gal Spill

Variable Costs:

| | | |
|---|---|---|
| Labor: (16 man-hr) | $ | 160 |
| Surface craft: | | |
| One large craft 4 hr @ $40/hr | | 160 |
| One barge 4 hr @ $20/hr | | 80 |
| Disposal: (2,700 gal) ($0.50/gal) | | 1,350 |
| | $ | 1,750 |

Fixed Costs:

| | | |
|---|---|---|
| Capital costs/yr, mechanical recovery equipment, $7,500/3 yr | | 2,500 |
| Maintenance costs/yr | | 750 |
| Storage costs/yr | | 600 |
| | $ | 3,850 |

Cost/incident for 50 incidents - $1,827

Cost/gal for
- 10 incidents - $0.79
- 50 incidents - $0.68
- 100 incidents - $0.66

Situation II: 270,000 gal Spill

Variable Costs:

| | | |
|---|---|---|
| Labor: (300 man-hr) | | 3,000 |
| Surface craft: | | |
| Four large craft - 120 hr @ $40/hr | | 4,800 |
| Four barges 120 hr @ $20/hr | | 2,400 |
| Disposal: (270,000 gal) ($0.50 gal) | | 135,000 |
| | $ | 145,200 |

Fixed Costs:

| | | |
|---|---|---|
| Capital costs/yr, mechanical recovery equipment, $30,000/3 yr | | 10,000 |
| Maintenance costs/yr | | 3,000 |
| Storage costs/yr | | 2,000 |
| | $ | 15,000 |

| | |
|---|---|
| Cost/incident for 10 incidents | - $146,700 |
| Cost/gal for 10 incidents | - $0.54 |

Situation III: 6,750,000 gal Spill

Variable Costs:

| | |
|---|---|
| Labor: (6,000 man-hr) | $ 60,000 |
| Surface craft: | |
| Four large craft 2,900 hr @ $40/hr | 116,000 |
| Four barges 2,900 hr @ $30/hr | 58,000 |
| Disposal: $(6.75 \times 10^6$ gal) ($0.50/gal) | 3,375,000 |
| | $ 3,609,000 |

Fixed Costs:

| | |
|---|---|
| Same as Situation II | $ 15,000 |

| | |
|---|---|
| Cost/incident | - $3,624,000 |
| Cost/gal - one incident | - $0.54 |

11. Sorbents/Suction Device Plus Containment Boom

A mechanical pumping device capable of recovering granulated sorbents from the water surface can be developed if it is not already available. The cost of such a unit is estimated to be $16,000 including spreader, storage and decanting tanks. The useful life is estimated to be about four years.

Situation I: 2,700 gal Spill

Variable Costs:

| | |
|---|---|
| Sorbents: | |
| (2,700 gal) ($0.10/gal) | 270 |
| Labor: (35 man-hr) | 350 |
| Surface craft: | |
| One large craft 4 hr @ $40/hr | 160 |
| Disposal: (2,700 gal) ($0.50/gal) | 1,350 |
| Place and clean boom | 320 |
| | $ 2,450 |

Fixed Costs:

| | |
|---|---|
| Capital costs/yr: | |
| Mechanical spreading and recovery equipment, $16,000/4 yr | $ 4,000 |
| Boom, $60,000/2 yr | 30,000 |
| Maintenance costs/yr | 4,600 |
| Storage costs/yr | 500 |
| | $ 39,100 |

Cost/incident for 50 incidents - $3,230
Cost/gal for
10 incidents - $2.36
50 incidents - $1.20
100 incidents - $1.05

Situation II: 270,000 gal Spill

Variable Costs:

| | |
|---|---|
| Sorbents: (270,000 gal) ($0.10/gal) | 27,000 |
| Labor: (800 man-hr) | 8,000 |
| Surface craft: Four large craft - 16 hr @ $40/hr | 640 |
| Disposal: (270,000 gal) ($0.50/gal) | 135,000 |
| Place and clean boom | 320 |
| | $ 170,960 |

Fixed Costs:

| | |
|---|---|
| Capital costs/yr | |
| Mechanical spreading and recovery equipment, $64,000/4 yr | 16,000 |
| Boom, $60,000/2 yr | 30,000 |
| Maintenance costs/yr | 9,400 |
| Storage costs/yr | 2,000 |
| | $ 57,400 |

Cost/incident for 10 incidents - $176,700
Cost/gal for 10 incidents - $0.65

Situation III: 6,750,000 gal Spill

Variable Costs:

| | |
|---|---|
| Sorbents: $(6.75 \times 10^6$ gal) (\$0.10/gal) | \$ 675,000 |
| Labor: (17,000 man-hr) | 170,000 |
| Surface craft: Four large craft 400 hr @ \$40/hr | 16,000 |
| Disposal $(6.75 \times 10^6$ gal) (\$0.50/ gal) | 3,375,000 |
| Place and clean boom | 320 |
| | \$ 4,236,320 |

Fixed Costs:

| | |
|---|---|
| Same as Situation II | \$ 57,400 |

Cost/incident - \$4,293,720
Cost/gal - One incident - \$0.64

12. Sorbents/Conveyor Plus Containment Boom

Situation I: 2,700 gal Spill

Variable Costs:

| | |
|---|---|
| Sorbents: (2,700 gal) (\$0.10/gal) | 270 |
| Labor: (35 man-hr) | 350 |
| Surface craft: One large craft 4 hr @ \$40/hr | 160 |
| Disposal: (2,700 gal) (\$0.50/gal) | 1,350 |
| Place and clean boom | 320 |
| | \$ 2,450 |

Fixed Costs:

| | | |
|---|---|---|
| Capital costs/yr | | |
| Spreader and mechanical recovery equipment, $50,000/4 yr | $ | 12,500 |
| Boom, $60,000/2 yr | | 30,000 |
| Maintenance costs/yr | | 4,250 |
| Storage costs/yr | | 500 |
| | $ | 51,750 |

Cost/incident for 50 incidents - $3,485
Cost/gal for
10 incidents - $2.82
50 incidents - $1.29
100 incidents - $1.10

Situation II: 270,000 gal Spill

Variable Costs:

| | | |
|---|---|---|
| Sorbents: (270,000 gal) ($0.10/gal) | | 27,000 |
| Labor: (800 man-hr) | | 8,000 |
| Surface craft: 4 large craft - 16 hr @ $40/hr | | 640 |
| Disposal: (270,000 gal) ($0.50 gal) | | 135,000 |
| Place and clean boom | | 320 |
| | $ | 170,960 |

Fixed Costs:

| | | |
|---|---|---|
| Capital costs/yr | | |
| Mechanical spreading and recovery equipment, $200,000/4 yr | | 50,000 |
| Boom, $60,000/2 yr | | 30,000 |
| Maintenance costs/yr | | 23,000 |
| Storage costs/yr | | 2,000 |
| | $ | 105,000 |

Cost/incident for 10 incidents - $181,460
Cost/gal for 10 incidents - $0.67

Situation III: 6,750,000 gal Spill

Variable Costs:

| | |
|---|---|
| Sorbents: (6.75 x $10^6$ gal) ($0.10/gal) | $ 675,000 |
| Labor: (17,000 man-hr) | 170,000 |
| Surface craft: Four large craft 400 hr @ $40/hr | 16,000 |
| Disposal: (6.75 x $10^6$ gal) ($0.50/gal) | 3,375,000 |
| Place and clean boom | 320 |
| | $ 4,236,320 |

Fixed Costs:

| | |
|---|---|
| Same as Situation II | $ 105,000 |

Cost/incident - $4,341,320
Cost/gal – one incident - $0.64

## IDENTIFICATION OF MOST COST EFFECTIVE SYSTEMS

The cost analysis shows that the cost per gallon to treat oil varies with the spill size and frequency. The cases and parameters used are believed to represent the most probable situations where oil spills of 2,700, 270,000 and 6,750,000 gallon sizes would require cleanup activity to prevent oil contamination of resources. Cost data were combined with the effectiveness indices by dividing the cost/gallon of oil treated for each spill size and system by the effectiveness index for each spill size and system. These are shown in Tables 8, 9, 10 and 11. The system having the lowest cost/effectiveness ratio is the most favorable. For the small spills, such as caused by personnel errors, the cost effectiveness is frequency dependent and the choice of system then depends on the number of spills of the small size which require treatment.

There are several practical matters to consider in the selection of these systems. One of these is that presently available booms have not been shown to be effective in open sea conditions. Parting of the boom, frequent overtopping in 5 foot waves, capsizing and oil carryunder in currents or towing conditions exceeding 1 to 1-1/2 knots are the principal deficiencies.

Thus, a system using a containment boom cannot be considered practically effective if reliance is placed on the boom. Nevertheless it was assumed that a boom designed for open seas could function for a limited time, though inefficiently, to slow the spread of oil or gather and thicken it for skimming or burning operations. Another consideration is that burning agents could only be evaluated for contained Navy Special or Bunker C and uncontained Bunker C. This is because the other products, JP-5, Distillate Fuel and uncontained Navy Special spread or disperse and evaporate so rapidly that they would likely be too thin for burning agents by the time equipment arrived. (A 270,000 gallon spill of JP-5 or Distillate Fuel spreads to less than the critical thickness for burning agents in about two hours; for a 2,700 gallon spill it is a little over 10 minutes.) A third consideration is that if burning agents are applied to oil that is surrounding or escaping from a vessel, it will pose a serious threat to the vessel itself. Smoke pollution near population centers is also an objectionable aspect of burning.

Thus the decision to use burning agents is dependent on location of the spill, type of oil and safety of the ship or other valuable property. For these reasons, burning does not represent a practical universal system even though its cost effectiveness for certain oils is favorable.

It is recognized that a system is desired which will provide a technique to contain oil which has escaped from and is surrounding a ship and collect or treat the escaped oil until salvage ships reach the scene. A reliable system to perform this function is not known to exist at the present time.

Based on the effectiveness analysis, the most cost effective systems for removing or dispersing oil from open waters are:

(1) Chemical burning agents applied to Bunker C prior to emulsification or to Navy Special when the slick is thick enough for burning. This method would be restricted to areas away from the ship and other valuable property and to areas where the smoke would not be considered a pollution problem. As pointed out previously, this system is not a practical universal system because of the

Table 8. Cost Summary – Situation 1

| System | Situation 1 – 2,700 Gal Spill | | | |
|---|---|---|---|---|
| | Cost/gal 10 incidents | Cost/gal 50 incidents | Cost/gal 100 incidents | Cost/Incident 50 incidents |
| 1. Chemical dispersants directly on spill | $0.86 | $0.80 | $0.79 | $ 2,140 |
| 2. Chemical dispersants plus containment | 2.19 | 1.16 | 1.02 | 3,125 |
| 3. Advancing skimmer | 1.30 | 0.77 | 0.70 | 2,060 |
| 4. Gellants/conveyor | 4.30 | 3.79 | 3.72 | 10,200 |
| 5. Gellants/conveyor plus containment | 5.65 | 4.15 | 3.96 | 11,200 |
| 6. Burning agents | | | | |
| a. Cellated glass | 0.29 | 0.26 | 0.25 | 620 |
| b. Silicon dioxide | 0.15 | 0.13 | 0.12 | 300 |
| 7. Burning agents plus containment | | | | |
| a. Cellated glass | 1.80 | 0.57 | 0.41 | 1,530 |
| b. Silicon dioxide | 1.78 | 0.53 | 0.38 | 1,440 |
| 8. Advancing skimmer plus containment | 2.48 | 0.96 | 0.77 | 2,590 |
| 9. Sorbents/conveyor | 1.46 | 0.93 | 0.86 | 2,490 |
| 10. Endless belts on water surface | 0.79 | 0.68 | 0.66 | 1,830 |
| 11. Sorbents/suction device plus containment | 2.36 | 1.20 | 1.05 | 3,230 |
| 12. Sorbents/conveyor plus containment | 2.82 | 1.29 | 1.10 | 3,485 |

Table 9. Cost Summary – Situations II & III

| System | Situation II 270,000 gal Spill: Cost/gal 10 incidents | Situation II 270,000 gal Spill: Cost/incident 10 incidents | Situation III 6,750,000 gal Spill: Cost/gal 1 incident | Situation III 6,750,000 gal Spill: Cost/incident 1 incident |
|---|---|---|---|---|
| 1. Chemical dispersants directly on spill | $0.61 | $165,000 | $0.61 | $ 4,114,000 |
| 2. Chemical dispersants plus containment | 0.62 | 169,000 | 0.61 | 4,147,000 |
| 3. Advancing skimmer | 0.60 | 160,000 | 0.57 | 3,836,000 |
| 4. Gellants/conveyor | 3.56 | 960,000 | 3.54 | 23,665,000 |
| 5. Gellants conveyor plus containment | 3.57 | 964,000 | 3.55 | 23,890,000 |
| 6. Burning Agents | | | | |
| a. Cellated glass | 0.16 | 38,000 | 0.18 | 1,051,000 |
| b. Silicon dioxide | 0.02 | 4,690 | 0.02 | 106,000 |
| 7. Burning agents plus containment | | | | |
| a. Cellated glass | 0.07 | 18,400 | 0.06 | 517,000 |
| b. Silicon dioxide | 0.04 | 9,100 | 0.03 | 160,000 |
| 8. Advancing skimmer plus containment | 0.58 | 156,000 | 0.55 | 3,696,000 |
| 9. Sorbents/conveyor | 0.66 | 178,000 | 0.55 | 4,308,000 |
| 10. Endless belts on water surface | 0.54 | 147,000 | 0.54 | 3,624,000 |
| 11. Sorbents suction device plus containment | 0.65 | 177,000 | 0.64 | 4,294,000 |
| 12. Sorbents conveyor plus containment | 0.67 | 181,000 | 0.64 | 4,341,000 |

Table 10 Cost Effectiveness Ratios for Different Frequencies of Situation 1 - 2,700 Gal Spill

| System | Effectiveness Index | Cost Gallon 10 Spills | Cost Gallon 50 Spills | Cost Gallon 100 Spills | Cost Effectiveness Ratios 10 Spills | Cost Effectiveness Ratios 50 Spills | Cost Effectiveness Ratios 100 Spills |
|---|---|---|---|---|---|---|---|
| 1. Chemical dispersants directly on spill | 88 | $0.56 | $0.80 | $0.79 | 0.00978 | 0.00910 | 0.00898 |
| 2. Chemical dispersants plus containment | 61 | 2.19 | 1.16 | 1.02 | 0.0359 | 0.0191 | 0.0167 |
| 3. Advancing skimmer | 55 | 1.30 | 0.77 | 0.70 | 0.0236 | 0.0140 | 0.0127 |
| 4. Gellants conveyor | 52 | 4.30 | 3.79 | 3.72 | 0.0826 | 0.0729 | 0.0715 |
| 5. Gellants conveyor plus containment | 44 | 5.65 | 4.15 | 3.96 | 0.128 | 0.0945 | 0.0900 |
| 6. Burning Agents | | | | | | | |
| a. Cellulated glass | 34 | 0.29 | 0.26 | 0.25 | 0.00854 | 0.00765 | 0.00735 |
| b. Silicon dioxide | 34 | 0.15 | 0.13 | 0.12 | 0.00441 | 0.00382 | 0.00353 |
| 7. Burning agents plus containment | | | | | | | |
| a. Cellulated glass | 26 | 1.80 | 0.57 | 0.41 | 0.0692 | 0.0219 | 0.0158 |
| b. Silicon dioxide | 26 | 1.78 | 0.53 | 0.38 | 0.0685 | 0.0204 | 0.0146 |
| 8. Advancing skimmer plus containment | 49 | 2.48 | 0.96 | 0.77 | 0.0506 | 0.0196 | 0.0157 |
| 9. Sorbents conveyor | 43 | 1.46 | 0.93 | 0.86 | 0.0340 | 0.0216 | 0.0200 |
| 10. Endless belts on water surface | 40 | 0.79 | 0.68 | 0.66 | 0.0198 | 0.0170 | 0.0165 |
| 11. Sorbents suction device plus containment | 41 | 2.36 | 1.20 | 1.05 | 0.0575 | 0.0293 | 0.0256 |
| 12. Sorbents conveyor plus containment | 41 | 2.82 | 1.29 | 1.10 | 0.0688 | 0.0315 | 0.0268 |

Table 11. Cost Effectiveness Ratios – All Spill Sizes

| System | Effectiveness Indices: I 2,700 Gal | Effectiveness Indices: II 270,000 Gal | Effectiveness Indices: III 6,750,000 Gal | Cost/Gallon: I-100% 2,700 Gal | Cost/Gallon: II-10% 270,000 Gal | Cost/Gallon: III-1% 6,750,000 Gal | Cost Effectiveness Ratios: Sit. I | Cost Effectiveness Ratios: Sit. II | Cost Effectiveness Ratios: Sit. III |
|---|---|---|---|---|---|---|---|---|---|
| 1. Chemical dispersants directly on spill | 82 | 79 | 62 | 0.79 | 0.61 | 0.61 | 0.00898 | 0.00772 | 0.00984 |
| 2. Chemical dispersants plus containment | 61 | 53 | 37 | 1.02 | 0.62 | 0.61 | 0.0167 | 0.0117 | 0.0165 |
| 3. Advancing skimmer | 55 | 39 | 39 | 0.70 | 0.60 | 0.57 | 0.0127 | 0.0154 | 0.0146 |
| 4. Gellants conveyor | 52 | 44 | 36 | 3.72 | 3.56 | 3.54 | 0.0715 | 0.0816 | 0.0983 |
| 5. Gellants conveyor plus containment | 44 | 44 | 36 | 3.96 | 3.57 | 3.55 | 0.0900 | 0.0812 | 0.0987 |
| 6. Burning agents | | | | | | | | | |
| a. Cellulated glass | 34 | 34 | 52 | 0.25 | 0.16 | 0.18 | 0.00735 | 0.00471 | 0.00346 |
| b. Silicon dioxide | 34 | 34 | 52 | 0.12 | 0.02 | 0.02 | 0.00353 | 0.000588 | 0.000385 |
| 7. Burning agents plus containment | | | | | | | | | |
| a. Cellulated glass | 26 | 44 | 44 | 0.41 | 0.07 | 0.08 | 0.0158 | 0.00159 | 0.00182 |
| b. Silicon dioxide | 26 | 44 | 44 | 0.38 | 0.04 | 0.03 | 0.0146 | 0.000910 | 0.000682 |
| 8. Advancing skimmer plus containment | 49 | 33 | 27 | 0.77 | 0.58 | 0.55 | 0.0157 | 0.0176 | 0.0204 |

Table 11. Cost Effectiveness Ratios – All Spill Sizes (Continued)

| System | Effectiveness Indices I 2,700 Gal | II 270,000 Gal | III 6,750,000 Gal | Cost/Gallon I-100 @ 2,700 Gal | II-10 @ 270,000 Gal | III-1 @ 6,750,000 Gal | Cost Effectiveness Ratios Sit. I | Sit. II | Sit. III |
|---|---|---|---|---|---|---|---|---|---|
| 9 Sorbents conveyor | 43 | 35 | 29 | 0.86 | 0.66 | 0.64 | 0.0200 | 0.0188 | 0.0221 |
| 10 Endless belts on water surface | 40 | 37 | 29 | 0.56 | 0.54 | 0.54 | 0.0165 | 0.0146 | 0.0186 |
| 11 Sorbents suction device plus containment | 41 | 33 | 19 | 1.05 | 0.65 | 0.64 | 0.0256 | 0.0197 | [illegible] |
| 12 Sorbents conveyor plus containment | 41 | 31 | 19 | 1.10 | 0.67 | 0.64 | [illegible] | 0.0216 | 0.0337 |

restrictions on oil type, thickness, emulsification, and location. This system would be improved if seaworthy fireproof booms were available to contain oil in thick layers for burning.

(2) Chemical dispersants applied directly to the slick where the spill is one mile or more from shore. This system appears to be the optimum choice for a universal system at the present time. The effectiveness of this system would be improved if seaworthy booms were available to prevent spread of oil.

(3) Advancing skimmers or weirs for small and intermediate spills, 2,700 to 270,000 gallons. Such a system was used to collect up to 25 barrels/day (about 1,000 gals/day) during the Santa Barbara Channel incident.

Large offshore workboats or similar craft could be equipped with detachable skimmer booms on each side with associated pumps to collect up to 50 barrels/day each. For major spills in the 6,750,000 gallon category, the recovery rate is insufficient unless large numbers of vessels are used; e.g. to cleanup 6,750,000 gallons in 5 days would require about 600 vessels recovering at 2,000 gals/day.

Considering the restraints listed previously, it is concluded that the most practical universal system for treating oil spills on open waters is chemical dispersants applied directly to the slick. Where feasible, a containment boom designed for open seas application should be deployed. Even though it may eventually fail or be ineffective, it will slow the spread of oil for a period of time. The oil which escapes may still be treated by dispersants. Where regulations prohibit the use of dispersants, burning (where feasible), or mechanical removal by skimmer devices should be employed. In this regard, the development of improved skimmers, cited previously in this report, holds much promise for the future. This method, which avoids the ever-present objection of adding to pollution by smoke or chemicals, will likely eventually produce a workable system.

In view of this, it would not appear justifiable at the present time to invest in any significant amount of skimming equipment. For disaster type situations, the use of chemical dispersants applied directly to the spill, chemical dispersants using containment, and burning are the three most cost effective systems presently available.

## F. DEPLOYMENT PLAN

The strategic storage of equipment and materials (or the equivalent in commercial availability on short notice) at Emergency Ship Salvage Material (ESSM) pools located around the world would materially assist in their mobilization and deployment for combatting massive spills. A massive or disaster type spill is taken as being in the order of 6,750,000 gallons.

### MATERIAL POOL LOCATIONS

The following locations of material pools and bases is as provided by Naval Ships Systems Command

ESSM Pools

ESSM pools are located at:

NSD Newport Annex, Bayonne, New Jersey
NSD Guantanamo Bay, Cuba
NSC Oakland, California
NSC Pearl Harbor, Hawaii
Naval Industrial Reserve Shipyard, Balboa, C.Z.
NSD Guam, Marianas
NSD Subic Bay, Philippines
San Juan, Puerto Rico

Submarine Salvage Material Pools

Submarine salvage material pools are located at:

Boston, Mass.
Charleston, South Carolina
San Diego, California
Pearl Harbor, Hawaii

Special Material Pools

Special material pools are located at:

San Francisco, California
Port Hueneme, California (NCEL)
Washington, D.C.

ESSM Bases

ESSM bases are located at:

8th Army Logistical Command, Leghorn, Italy (Livorno)
NSY Boston, Mass.
NSY Philadelphia, Pa.
Naval Base Norfolk, Va.
Navy Station San Diego, California
NSY Charleston, S.C.
NSY San Francisco, California
NSY Puget Sound, Bremerton, Washington
Navy Station, Adak, Alaska
Ship Repair Facility, Yokosuka, Japan
Fleet Activities, Sasebo, Japan

## RECOMMENDED EQUIPMENT, MATERIAL AND STORAGE LOCATIONS

Recommendation for equipment and material to be available at selected locations are listed below. The basis for the recommendations is that the method to be used for combatting massive spills is chemical dispersing and that a boom or booms will also be deployed to assist in containing the oil and slowing its speed. The treatment would be supplemented by burning for Bunker C or thick slicks of Navy Special where burning is feasible. The amounts of materials recommended are not the total amounts required for complete treatment of a massive (6,750,000 gallons) spill. This is to avoid storage of materials and equipment in duplication which have a low frequency of use. Also, experience shows that it is rarely possible to locate and treat all oil involved in a spill, i.e., evaporation, natural dispersal and separation of the slicks can be expected to reduce the amount of oil to be treated. There is no way to accurately predict how much of the oil will require treatment.

### Equipment and Materials

It is recommended that amounts of equipment and materials be stored or be available at each designated location as follows:

1. Store on hand, or be able to obtain on four hours' notice, 20,000 gallons of chemical dispersant.
2. Store on hand six dispersant spray booms complete with engines, pumps, nozzles and hardware. Four should be rated at about 250 gpm and suitable for mounting on large surface craft (40-80'). Two should be rated at about 125 gpm and suitable for mounting on small craft carried on ARS vessels. Use of the dispersing system assumes 4 large craft at the scene, 2 small craft which initially disperse and perform their own mixing, 8 intermediate mixer craft (2 mixers per large application craft) and assumes tankage or storage space for approximately 5,000 gallons or more on each large craft. Replenishment of dispersants would require ARS or other tankage on the scene or return of the dispersing craft to shore.
3. Store on hand two eductors for ARS fire hoses to use in applying dispersants which are applied diluted.
4. Store on hand two booms designed for open sea conditions (up to 5 ft waves and 20 mph winds) each 3,000 ft in length. One should be fireproof.
5. Store on hand, or be able to obtain on four hours' notice, 2,000 lbs of silicon dioxide powder burning agent or 20 tons of cellated glass bead burning agent
6. Store on hand, four spreaders for burning agents compatible with the type of burning agent available, as recommended by the manufacturer of the burning agent. Spreaders should be suitable for mounting on intermediate or large craft.

### Storage Locations

It is recommended that the above-listed materials and equipment be located as follows

1. ESSM Pool at Bayonne, New Jersey for spill locations on the Atlantic Coast of the U.S. and Canada.
2. ESSM Pool at Guantanamo Bay, Cuba for spill locations along the Florida coast, the Gulf of Mexico, and the Caribbean Sea, which includes waters around the Greater Antilles, Canal Zone, and the northern coast of South America.
3. ESSM Pool at Oakland, California for spill locations on the Pacific coast of the U.S., Canada and Mexico.
4. ESSM Pool at Pearl Harbor, Hawaii for spill locations around the Hawaiian and other Pacific islands.
5. ESSM Pool at Subic Bay, Philippines for spill locations around the Philippines, Japan, western Pacific islands, and other coasts and islands in this area.
6. 8th Army Logistical Command Base, Leghorn Italy (Livorno) for spill locations in the Mediterranean Sea and European and African coasts of the North Atlantic Ocean

Each storage location is fitted with the nucleus to rapidly initiate spill treatment and the capability exists to supplement supplies by transfer from ESSM pools to maintain treatment if additional materials and equipment cannot be furnished locally. Air transport is suggested for material and equipment transfer because the time factor is critical in treating oil spills. In the use of surface craft, it is assumed that commercial craft available near the scene would be utilized, supplemented by Navy craft, if available.

## EQUIPMENT FOR ARS VESSELS

It is recommended that the following equipment and materials be located aboard ARS vessels for use against massive spills. In the event of space restrictions, they may be obtained from ESSM Pools when the need arises. Materials and equipment are listed in the order of priority.

### Materials and Equipment for Dispersing

1. 20,000 gallons of chemical dispersant (in drums).
2. Two dispersant spray booms complete with engines, pumps, nozzles and hardware for mounting on the small workboats (30 to 35 ft) located on the ARS. Each boom system should be rated at approximately 125 gpm.
3. Two eductors for use on ARS fire hoses to enable use of dispersants which require dilution.
4. Depending on the location of the spill, the four dispersant spray booms located at ESSM pools may be located aboard ARS vessels or transported to workboats near the scene by other methods such as airlift.

### Containment Equipment

Two booms designed for open sea conditions (up to 5 ft waves and 20 mph winds) each 3,000 ft in length. One boom should be fireproof

Materials and Equipment for Burning

1. 2,000 lbs of silicon dioxide powder burning agent or 20 tons of cellated glass bead burning agent.
2. Four spreaders for burning agents compatible with the type of burning agent to be used, as recommended by the manufacturer of the burning agent.

It is recommended that dispersants be stored and transported in 55 gallon drums to provide longer shelf life by preventing loss of solvent from evaporation and to enable use on vessels not equipped with tankage.

The above listed material and equipment is the same as recommended for storage at ESSM Pools. It provides for initiating treatment of a massive spill by ARS vessels using chemical dispersing, booming to slow the spread of oil, and burning of Bunker C or thick slicks of Navy Special where it is feasible. The on-board small craft may be used to first deploy the booms around the ship or to contain large slicks, insofar as practicable, and then initiate dispersing or burning of slicks which may be threatening shorelines. The ARS, with its fire hoses and monitors may also perform dispersing or burning operations, if, for example, oil offloading or salvage operations cannot be done immediately. Treatment of spill incidents with the potential of releasing on the order of 6,750,000 gallons will require additional workboats for dispersing or burning operations, and additional materials. As stated previously, there is no way to predict how much of the oil will require treatment and the amounts of additional materials and equipment to supplement the operation will have to be determined for each case. Chemical dispersing of all of a cargo of 6,750,000 gallons would require about 1,350,000 gallons of dispersant.

## G. RECOMMENDATIONS FOR FUTURE RESEARCH

The evaluation of the systems considered in this study brought out shortcomings in several of the proposed methods and equipment for treating oil spills. Potential improvements in methods and equipment have been identified. These include systems now at the development stage which are not amenable to accurate cost effectiveness analysis. The items believed feasible and capable of improving effectiveness and economics of spill treatment within the scope of this study are:

### IMPROVEMENT TO EQUIPMENTS AND METHODS

- Development of a boom for use in open sea conditions. A boom is needed which can maintain its integrity in moderately severe weather and function to contain spilled oil in conditions prevailing 90% of the time on open seas. The primary benefit of a boom would be to prevent further spreading and contain spills to allow treatment before the oil reaches shore. The U.S. Navy presently has a boom designed by the Supervisor of Salvage for mooring in open waters. The boom can be constructed of readily available materials. It is described further on page 45 and in Appendices C and D.[50] The U.S. Coast Guard is sponsoring research on development of lightweight and heavy duty booms for open sea use and several

manufacturers have booms under development or in production which are claimed to be suitable for open sea conditions. These developments should be investigated.

- Detailed delineation of a test for booms for open sea use and sea trials to prove out their utility, reliability, strength, capacity and deployment under open sea conditions.
- Improvement of existing or development of new advancing skimmers. Some new concepts for advancing skimmers are presently being developed under support by the American Petroleum Institute, the Federal Water Quality Administration and the U.S. Coast Guard. The U.S. Navy should investigate and take advantage of these improvements.

## INNOVATIONS

- Development of automated mechanical methods of collecting and removing (from water surfaces) oil agglomerates which have been formed by the use of sorbents. Adaptation of kelp or aquatic harvesting equipment is one approach to this method.
- Investigation of the use of emulsified fuel oils (Bunker C and Navy Special). Work by Sonics International, discussed previously, indicates that cargo which is emulsified prior to loading could be expected to disperse within a few hours if it were spilled. Their study suggests that fuel oil can be used as a ship fuel without emulsion break-back. A study should be performed to determine the practicability and reliability of using emulsified fuel oils for Navy ship fuel.

## SPILL TECHNOLOGY

- Development of accurate methods for estimating or measuring spill volumes. Such methods are needed to determine application rates for treatment agents. Additional information is needed on the evaporation rates of spilled oil products.
- Investigation of the tendency of Navy Special to form water-in-oil emulsions in exposure to open sea conditions. This data will assist in determining the type of equipment and methods most effective on Navy Special since the treatment and recovery of emulsions presents problems quite different from oils not emulsified.
- Determination of the most cost effective dispersants for use in treating the oils used by U.S. Navy ships. Many dispersants function most effectively on light oils. Testing to determine the most effective agents for the persistent oils, Navy Special and Bunker C, would result in economy in treating these types of oils. The same is true for treating agents for JP-5 and Distillate Fuel. Effectiveness testing procedures being developed under the sponsorship of the American Petroleum Institute would be helpful in such determinations.
- Determination of the most cost effective burning agents for specific oils used by the U.S. Navy, for reasons similar to those given above for dispersants. In this case, the oils most amenable to burning are Bunker C and Navy Special because of the influence of film thickness.

- Determination aand recording of available sites for disposal of recovered oil, including processing facilities, storage facilities, pits or landfill sites. Knowledge of available disposal locations and facilities in areas of possible spill locations (heavily traveled routes, hazardous navigational locations) and near Naval installations could be expected to result in economies and improved efficiency in disaster type situations.
- Provision for a formal training program for personnel charged with spillage countermeasures at all Naval installations. The program should be developed for massive spill situations, stress conservation and hazards aspects, and be presented by recognized authorities.
- Inventory of available equipment, commercial, Navy, Port Authorities, etc. at major U.S. ports and harbors to enable mobilization of such equipment in the event of a disaster type spill.
- Development of a detailed response plan for coping with nominal and massive spills for all potential petroleum products potentially involved in spillage. Fall back positions should be included.

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# APPENDIX A

# DETAILED ENVIRONMENTAL AND GEOGRAPHIC DATA

# APPENDIX A

## DETAILED ENVIRONMENTAL AND GEOGRAPHIC DATA

This appendix contains the basic information from which the report section entitled "Reference Environments and Geography" was derived. It includes detailed environmental and hydrologic information of the world's oceans in the form of charts, meteorological data, and tabulated data describing the type of resources vulnerable to damage in the reference marine areas. Additionally presented are similar data for nearby ports and harbors frequented by U.S. Naval Oilers and Gasoline Tankers. This material is included because of the greater abundance of data on the environmental features. These features, although generally modified by protective land masses were helpful in assessing the reference marine areas.

Table A-1 lists the environmental and physical features of selected nearby ports and harbors.

Table A-2 lists the nearby features of selected ports, including the resources which would be threatened by oil spillage.

Table A-3 presents data obtained from the decennial census of the United States climate, summary of hourly observations.

Table A-4 is a summary of predicted wave dimensions expected to prevail 90% of the time. A worldwide average was calculated from these data.

Figures A-1 thru A-8 are reprinted from the U.S. Navy Marine Climatic Atlas of the World Vol. VIII and present data on percentage frequency of sea and swell, and gales and wind for the four seasons.

Figures A-9 and A-10 illustrate the mean sea surface temperature and the average wind direction of the world for the month of February.

Figure A-11 illustrates the average world surface current direction.

Table A-1. Environmental and Physical Features of Ports

| | Area, square naut mi | Mean Tide, ft | Max Tide, ft | Max Current, knots | Prevailing Winds, knots | High Winds, knots | Precip, in. | Mean Sea Temp, °F | Mean Air Temp, °F | Shoreline, naut mi | Tidal Prism, cu naut mi |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Puget Sound** | 767 | 8 | 15 | 5.0 | 10 S | 61 S | 40 | 50 | 50 | 1157 | 1.27 |
| Naval Shipyard--Bremerton | | 8.0 | 14.7 | 1.5 | 10 S | 60 S | 40 | 50 | 50 | | |
| Naval Fuel Depot--Manchester | | 7.6 | 14.8 | 1.2 | 10 S | 60 S | 40 | 50 | 50 | | |
| Naval Supply Center--Seattle | | 7.6 | 14.7 | 0.5 | 8.3 SSW | 48SSW | 38.9 | 50 | 51.1 | | |
| Naval Torpedo Station--Keyport | | 8.0 | 15 | 1.1 | 10 S | 60 S | 40 | 50 | 50 | | |
| Naval Ammunition Depot--Bangor | | 7.9 | 14.9 | 1.0 | 10 S | 60 S | 38 | 50 | 50 | | |
| **San Francisco Bay** | 309 | 4 | 9 | 6.5 | 9 | 54 SW | 18.7 | 55.6 | 56.0 | 160 | 0.26 |
| Naval Shipyard--Mare Island | | 5 | 10 | 2.4 | 9 WNW | 54 SW | 18.7 | 55.6 | 56.0 | | |
| Naval Shipyard--Hunters Point | | 4 | 9 | 1.8 | 9 WNW | 54 SW | 18.7 | 55.6 | 56.0 | | |
| Naval Station--Treasure Island | | 4 | 9 | 3.1 | 9 WNW | 54 SW | 18.7 | 55.6 | 56.0 | | |
| Naval Air Station--Alameda | | 4 | 9 | 1.8 | 9 WNW | 54 SW | 18.7 | 55.6 | 56.0 | | |
| Naval Fuel Depot--Point Molate | | 4 | 9 | 1.8 | 9 WNW | 54 SW | 18.7 | 55.6 | 56.0 | | |
| **San Pedro Bay** | 13.8 | 3.8 | 9 | 1.0 | 6.3 W | 54 W | 12.6 | 61.8 | 61.9 | | |
| Naval Shipyard--Long Beach | | 3.8 | 9 | 1.0 | 6.3 W | 54 W | 12.6 | 61.8 | 61.9 | | |
| Naval Station--Long Beach | | 3.8 | 9 | 1.0 | 6.3 W | 54 W | 12.6 | 61.8 | 61.9 | | |
| Naval Fuel Depot--San Pedro | | 3.8 | 9 | 1.0 | 6.3 W | 54 W | 12.6 | 61.8 | 61.9 | | |
| **San Diego Bay** | 14 | 4.1 | 9 | 3.0 | 5.4 WNW | 44 SE | 10.4 | 61.4 | 63.2 | 28 | 0.0095 |
| Naval Station--San Diego | | 4.2 | 10 | 2.5 | 5.4 WNW | 44 SE | 10.4 | 61.4 | 63.2 | | |
| Naval Fuel Depot--Point Loma | | 4.1 | 9 | 3.0 | 5.4 WNW | 44 SE | 10.4 | 61.4 | 63.2 | | |
| **Pearl Harbor** | | 1 | 2 | 0.5 | 10 ENE | 58 SW | 21.9 | 78.1 | 75.9 | | |
| Naval Base--Pearl Harbor | | 1 | 2 | 0.5 | 10 ENE | 58 SW | 21.9 | 78.1 | 75.9 | | |

Table A-1. Environmental and Physical Features of Ports (Continued)

| | Mean Tide, ft | Maximum Current, knots | Prevailing Wind, knots | Direction | High Winds, knots | Direction | Precip, in. | Mean Sea Temp, °F | Mean Air Temp, °F |
|---|---|---|---|---|---|---|---|---|---|
| Massachusetts Bay | 9.5 | | 11.4 | SW | 56 | NNW | 42.77 | 50.3 | 51.4 |
| Naval Shipyard--Boston | 9.5 | 1.0 | 11.4 | SW | 56 | NNW | 42.77 | 50.3 | 51.4 |
| Narragansett Bay | 4.6 | | 9.7 | SW | | | 42 | 51.8 | 50.1 |
| Naval Base-Narragansett (Newport) | 4.6 | 1.1 | 9.7 | SW | | NW | 42 | 51.8 | 50.1 |
| Naval Air Station--Quonset Point | 4.6 | 0.6 | 9.7 | SW | | NW | 42 | 51.8 | 50.1 |
| Submarine Base--New London | 2.6 | 0.8 | | | | | 41 | 59.6 | 50.2 |
| Delaware Bay | 2.9 | | 8.3 | WSW | 63 | NW | 42.48 | 57.4 | 53.5 |
| Naval Shipyard--Philadelphia | 2,9 | 2.4 | 8.3 | WSW | 63 | NW | 42.48 | 57.4 | 53.5 |
| Naval Shipyard--Portsmouth, Virginia | 1.9 | 4.0 | 9.0 | SW | 68 | S | 45 | 60 | 59.7 |
| Naval Supply Center--Norfolk, Virginia | 1.9 | 0.6 | 9.0 | SW | 68 | S | 44.94 | 60 | 59.7 |
| Naval Amphibious Base--Little Creek | 2.8 | 1.0 | 9.0 | SW | 68 | S | 45 | 60 | 59.7 |
| Charleston Harbor | 2.6 | 2.0 | 7.7 | NE | | | 49.16 | 68.0 | 65.0 |
| Naval Shipyard--Charleston | 2.6 | 2.0 | 7.7 | NE | | | 49.16 | 68.0 | 65.0 |
| Naval Station--Charleston | 2.6 | 2.0 | 7.7 | NE | | | 49.16 | 68.0 | 65.0 |
| Naval Fuel Depot--Charleston | 2.6 | 2.0 | 7.7 | NE | | | 49.16 | 68.0 | 65.0 |
| Naval Fuel Depot--Jacksonville | 1.2 | 1.0 | 7.6 | NW | 63 | E | 53.36 | 73.6 | 69.5 |
| Naval Station--Mayport | 1.2 | 3.1 | 7.6 | NW | 63 | E | 53 | 71.2 | 68.0 |
| Naval Station--Key West | 1.3 | 1.5 | 9.9 | ESE | 106 | NW | 39.99 | 79.4 | 76.8 |
| Naval Station--San Juan, Puerto Rico | 1.0 | 1.0 | 7.3 | ENE | 70 | NE | 64.21 | 81.0 | 78.0 |

Table A-2. Nearby Features

| | Recreational Beaches | Mud Flats | Kelp Beds | Estuaries | Boat Marinas | Industrial Facilities | Sport Fisheries | Commercial Fisheries | Commercial Shellfish |
|---|---|---|---|---|---|---|---|---|---|
| **Puget Sound** | | | | | | | | | |
| Naval Shipyard--Bremerton | Yes | Yes | Yes | No | Yes | Yes | Yes | No | No |
| Naval Fuel Depot--Manchester | Yes | No | Yes | No | No | Yes | Yes | No | No |
| Naval Supply Center--Seattle | Yes | No | No | No | No | Yes | Yes | No | No |
| Naval Torpedo Station--Keyport | Yes | Yes | Yes | Yes | Yes | Yes | Yes | No | Yes |
| Naval Ammunition Depot--Bangor | Yes | No | Yes | No | Yes | No | Yes | No | Yes |
| **San Francisco Bay** | | | | | | | | | |
| Naval Shipyard--Mare Island | No | Yes | No | Yes | Yes | Yes | Yes | No | No |
| Naval Shipyard--Hunters Point | No | Yes | No | Yes | Yes | Yes | Yes | No | No |
| Naval Station--Treasure Island | No | Yes | No | Yes | Yes | Yes | Yes | No | No |
| Naval Air Station--Alameda | No | Yes | No | Yes | Yes | Yes | Yes | No | No |
| Naval Fuel Depot--Point Molate | No | Yes | No | Yes | Yes | Yes | Yes | No | No |
| **San Pedro Bay** | | | | | | | | | |
| Naval Shipyard--Long Beach | No | No | No | No | Yes | Yes | Yes | No | No |
| Naval Station--Long Beach | No | No | No | No | Yes | Yes | Yes | No | No |
| Naval Fuel Depot--San Pedro | Yes | No | Yes | No | Yes | Yes | Yes | No | No |
| **San Diego Bay** | | | | | | | | | |
| Naval Station--San Diego | Yes | No | No | Yes | Yes | Yes | Yes | No | No |
| Naval Fuel Depot--Point Loma | Yes | No | Yes | No | Yes | Yes | Yes | No | No |
| **Pearl Harbor** | | | | | | | | | |
| Naval Base--Pearl Harbor | Yes | | | | | | Yes | | |

Table A-3. U. S. Weather Bureau Decennial Census

| | Percentage/Accumulated Percentage of Wind Speed, mph | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0–3 | 4–7 | 8–12 | 13–18 | 19–24 | 25–31 | 32–38 | 39–46 | 47 over | Calm | Average |
| Puget Sound (Seattle-Tacoma Airport, 1951-1960) | 13/13 | 16/29 | 35/64 | 26/90 | 8/98 | 2/100 | + | + | + | 10 | 11 |
| San Francisco (San Francisco International Airport, 1951-60) | 16/16 | 21/37 | 26/63 | 22/85 | 11/96 | 3/99 | + | + | + | 8 | 10 |
| San Diego (Lindbergh Field, 1951-60) | 28/28 | 38/66 | 28/94 | 6/100 | + | + | + | | | 6 | 6 |
| Pearl Harbor (Honolulu International Airport, 1951-60) | 9/9 | 17/26 | 27/53 | 32/85 | 12/97 | 2/99 | + | + | + | 1 | 12 |
| Boston (Logan International Airport, 1951-60) | 3/3 | 12/15 | 33/48 | 35/83 | 12/95 | 4/99 | 1/100 | + | + | 1 | 13 |
| Charleston, So. Carolina (Municipal Airport, 1951-60) | 12/12 | 28/40 | 35/75 | 19/94 | 4/98 | 1/99 | 1/100 | + | | 7 | 9 |
| Norfolk, Virginia (Municipal Airport, 1951-60) | 14/14 | 23/37 | 30/67 | 25/92 | 6/98 | 1/99 | 2/101 | + | + | 2 | 10 |
| San Juan, Puerto Rico | 15/15 | 28/43 | 27/70 | 25/95 | 4/99 | + | + | + | + | 9 | 9.1 |

| | Percentage/Accumulated Percentage of Wind Speed, knots | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0–3 | 4–10 | 11–21 | 22–27 | 28–40 | 41 over | Calm | Average |
| Long Beach, California (Municipal Airport, 1947-57) | 48/48 | 45/93 | 6/99 | 0.2/99.2 | 0.0 | 0.0 | 31 | 4 |

| | Percentage/Accumulated Percentage of Wind Speed, knots | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0–2 | 3–7 | 8–12 | 13–20 | 21–40 | 40 over | Calm |
| Quonset Point, Rhode Island | 7/7 | 18/25 | 27/52 | 32/84 | 15/99 | 1/100 | 3 |

Accumulated Percentage Frequency
For ≤ Upper Parameter of Range
of Wind Velocities

$0.0 < + < 0.5$ mph
$0.0 < \underline{.0} < 0.05$ knots

Table A-4. Offshore Wave Height Prediction for 90% Probability

| Area | Max. Wind Vel. 90% of Time MPH | Max. Significant Wave Height-Ft. | Min. Wave Length-Ft. | Average Wave Length-Ft. |
|---|---|---|---|---|
| Astoria | ≤16 | 3.3 | 23 | 59 |
| Eureka | ≤13 | 1.8 | 12.5 | 33 |
| San Francisco | ≤20 | 5.3 | 37 | 80 |
| San Diego | ≤11 | 1.0 | 7 | 20 |
| Massachusetts | ≤21 | 6.1 | 42.7 | 90 |
| Charleston | ≤16 | 3.3 | 23 | 59 |
| Norfolk | ≤18 | 4.6 | 32.2 | 71 |
| Hawaii | ≤20 | 5.3 | 37 | 80 |
| United Kingdom | ≤30 | 13.0 | 91 | 140 |

≤18.3 MPH Wind
≤5.0 Ft. Wave Height
90% Probability Worldwide Average

FEBRUARY GALES - WIND ≤ 10 KNOTS CHART 20

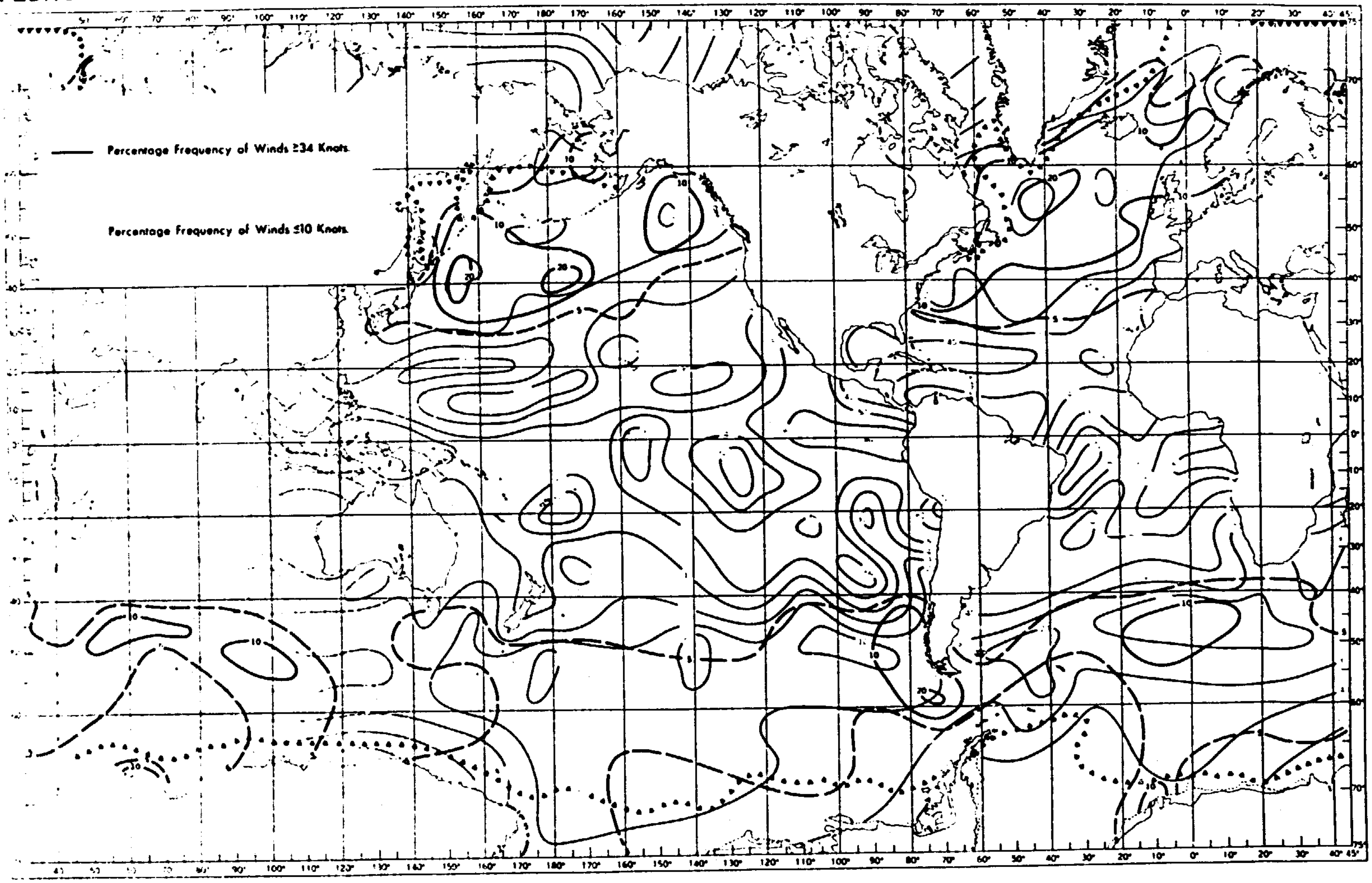


Figure A-1 Worldwide winds - February

MAY GALES - WIND ≤ 10 KNOTS CHART 51

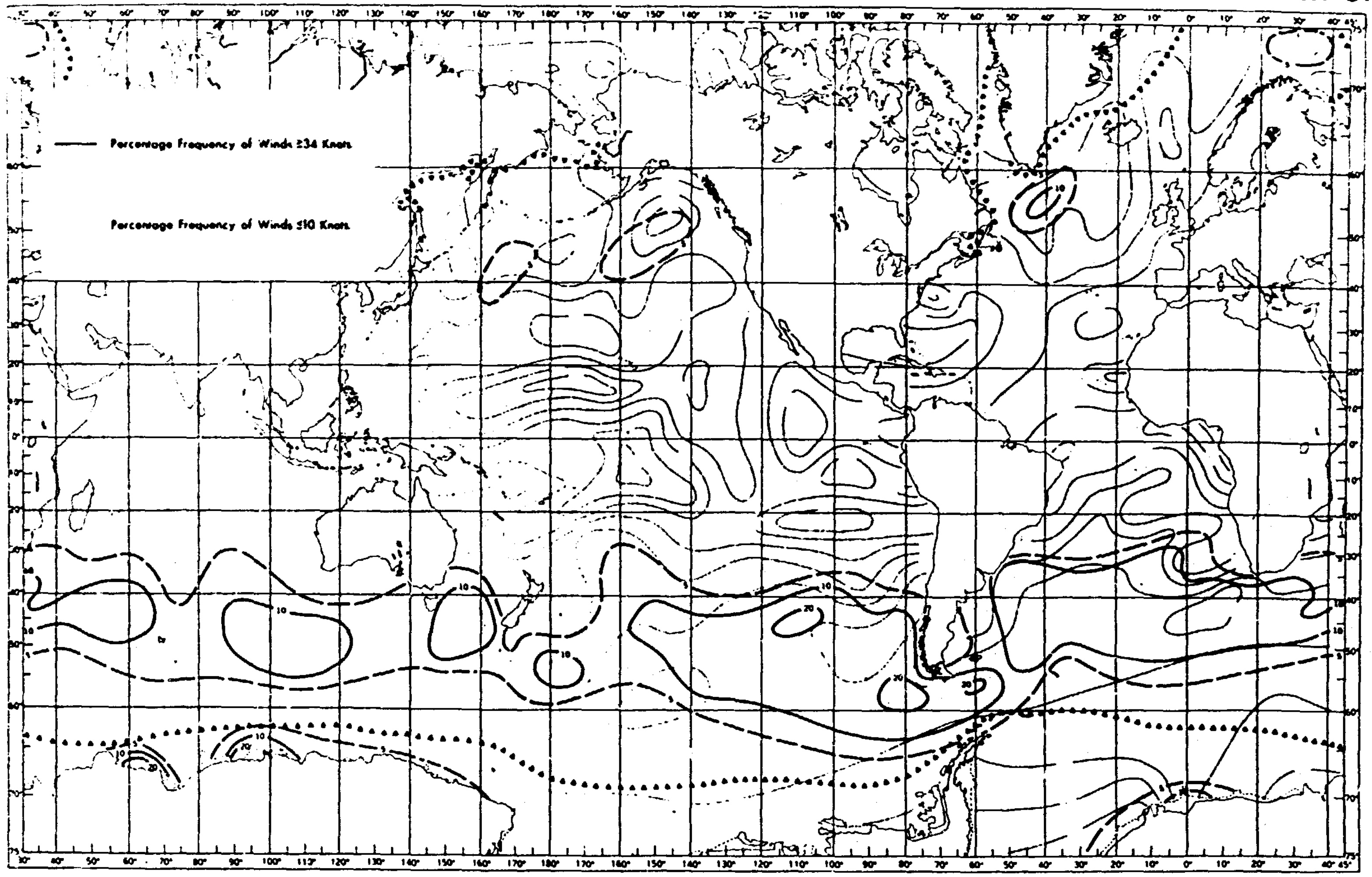


**Figure A-2 Worldwide winds - May**

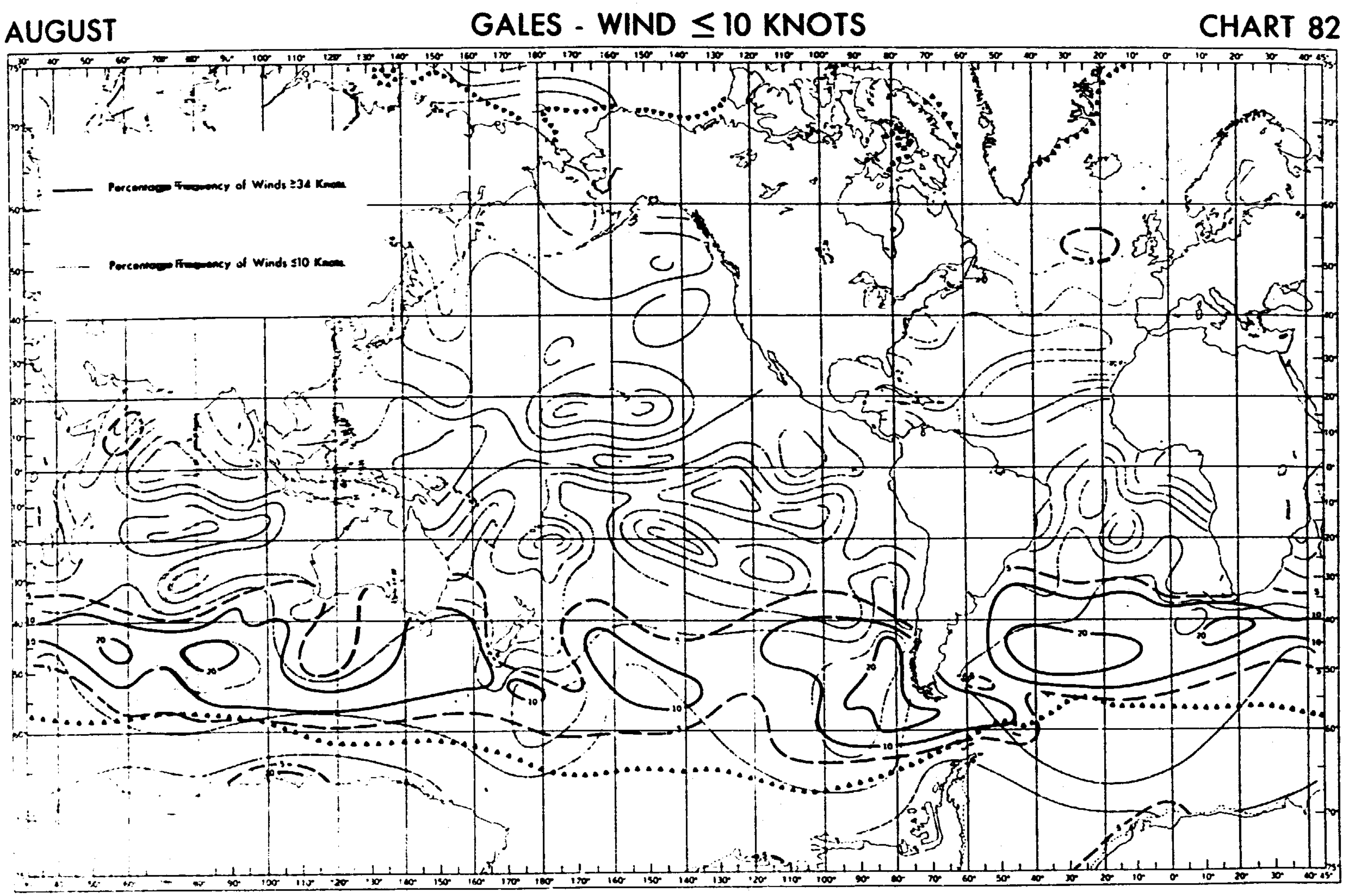


Figure A-3 Worldwide Winds - August

NOVEMBER GALES - WIND $\leq$ 10 KNOTS CHART 113

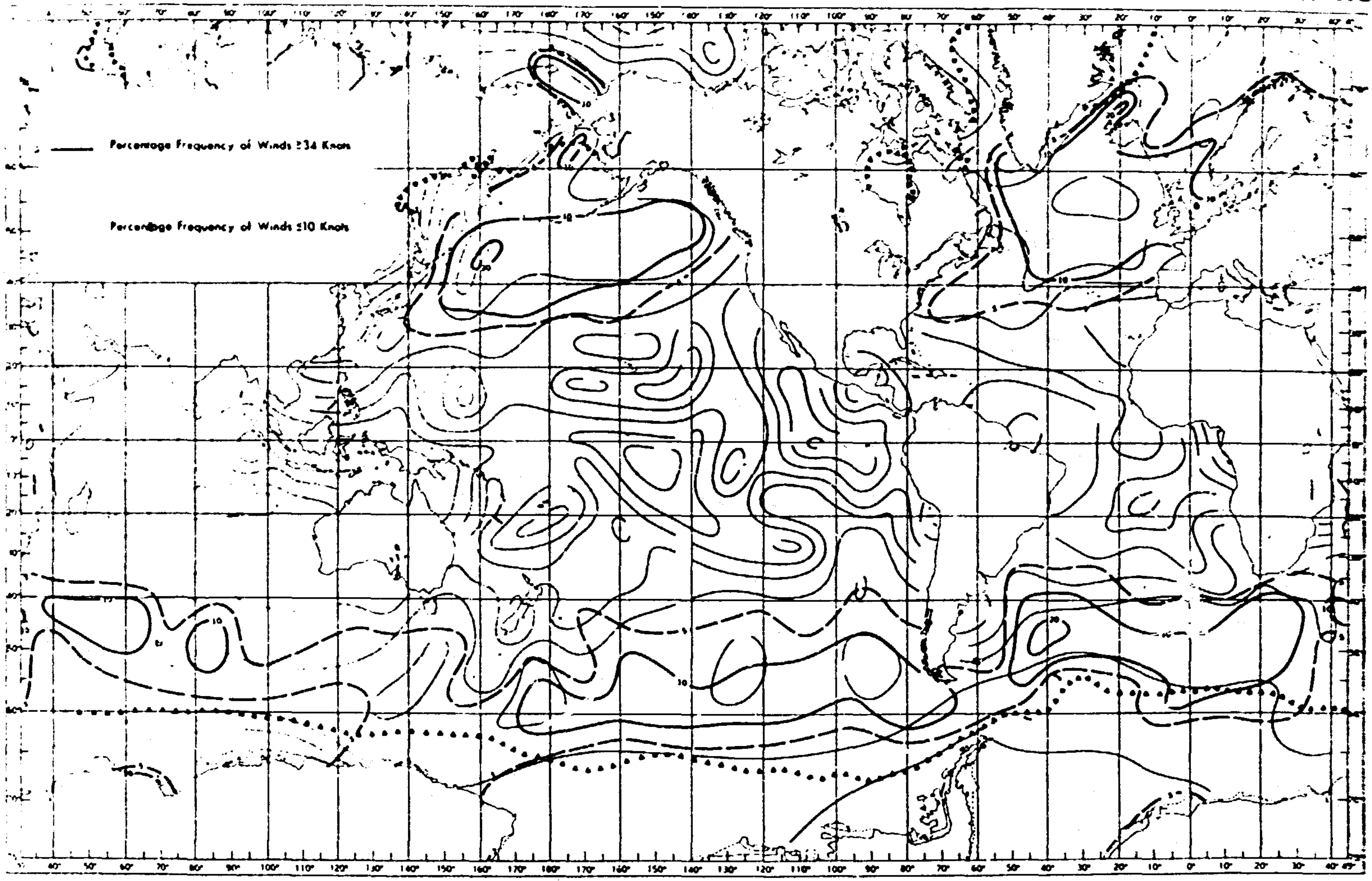


**Figure A-4 Worldwide winds - November**

FEBRUARY SEA AND SWELL CHART 22

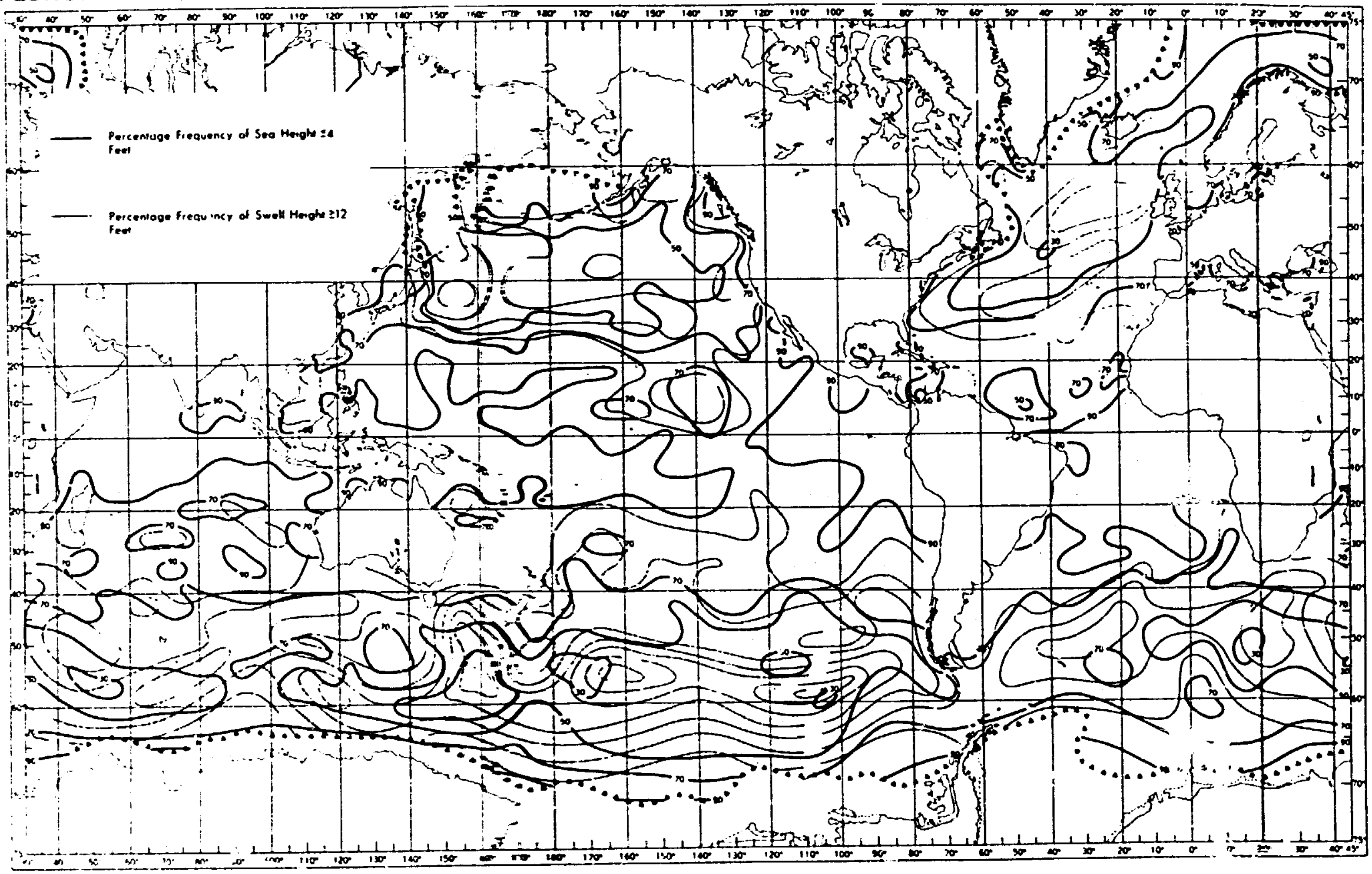


Figure A-5 Worldwide sea and swell - February

MAY SEA AND SWELL CHART 53

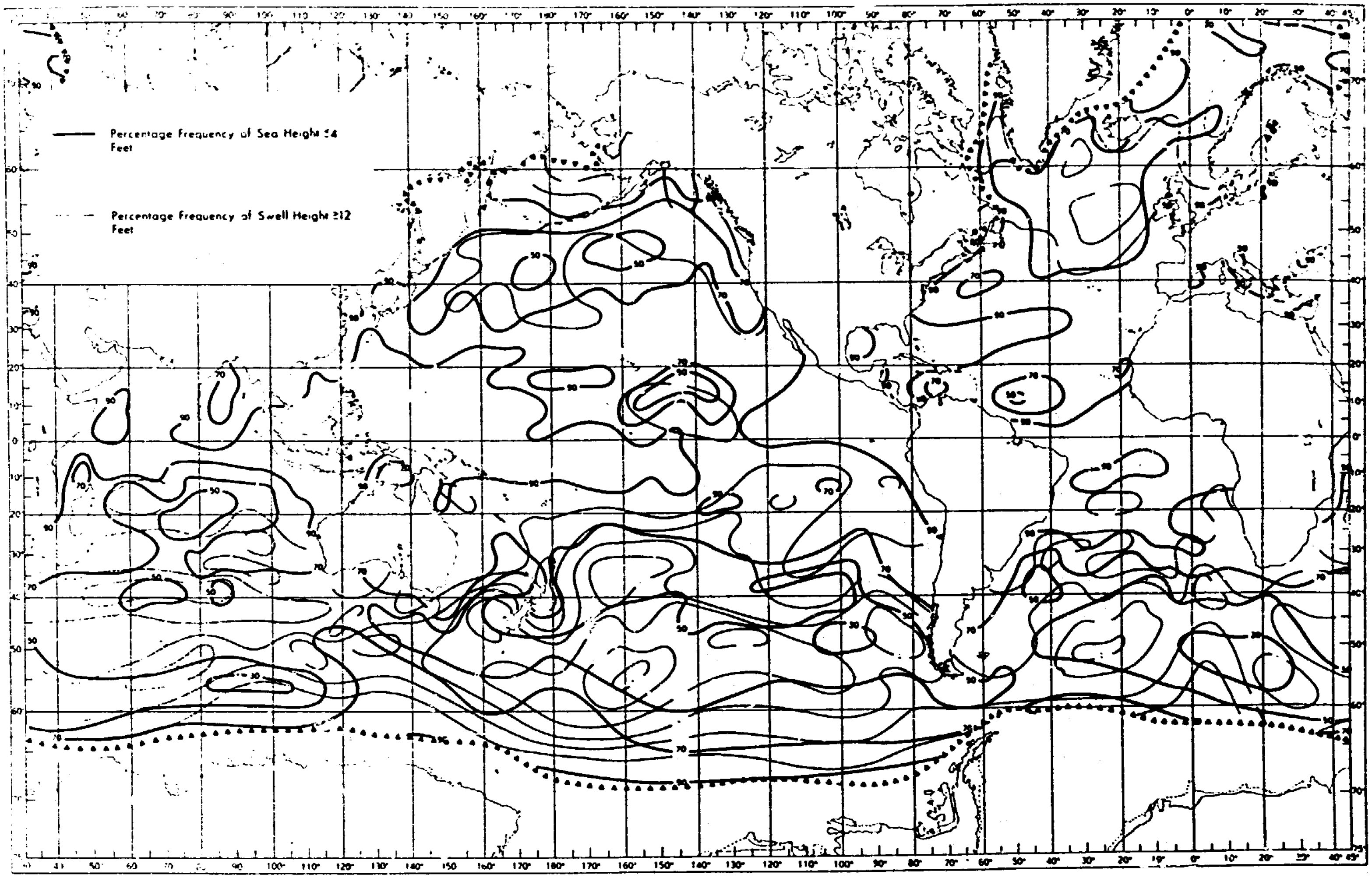


**Figure A-6 Worldwide sea and swell - May**

AUGUST SEA AND SWELL CHART 84

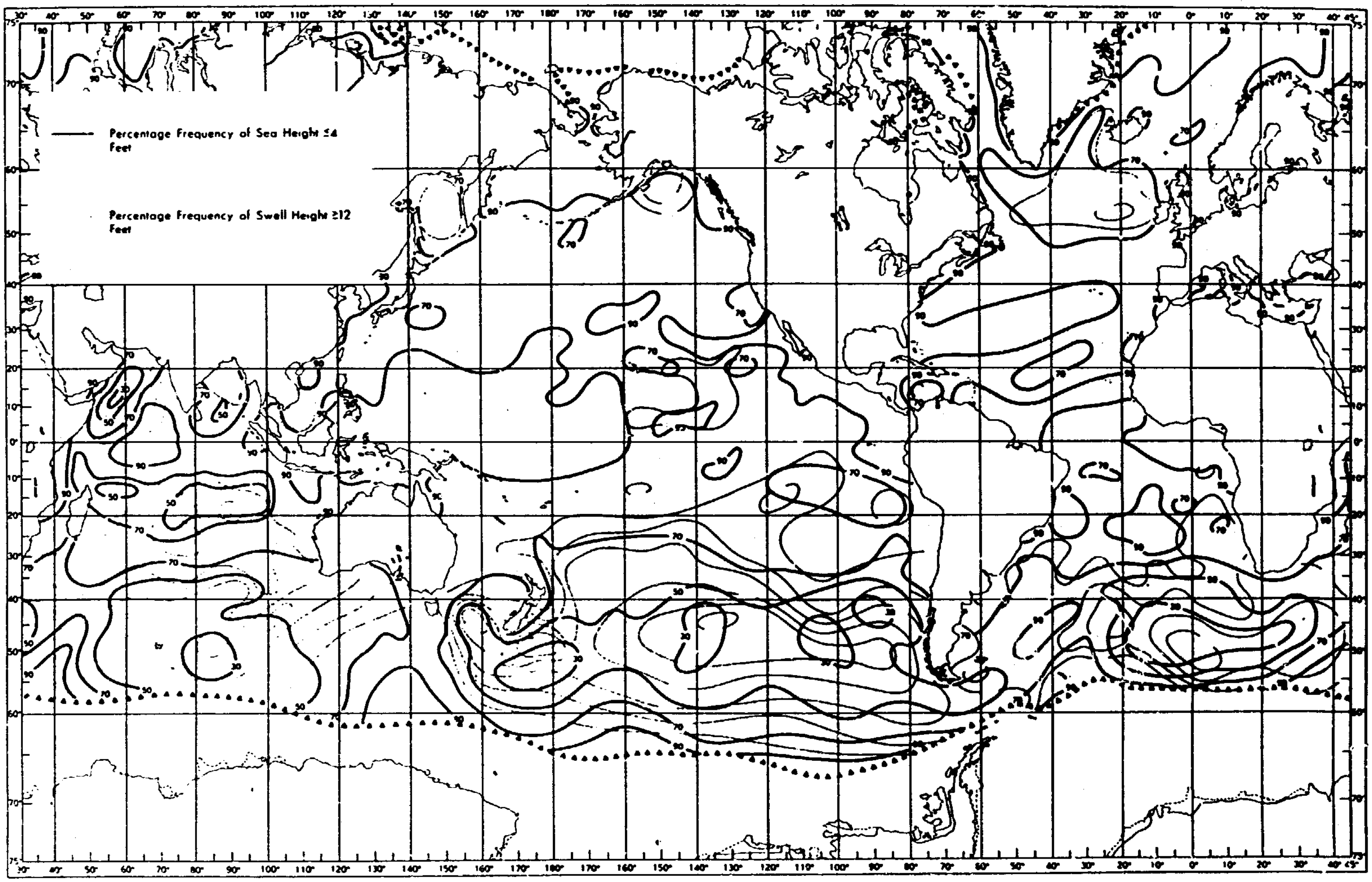


**Figure A-7 Worldwide sea and swell - August**

NOVEMBER SEA AND SWELL CHART 115

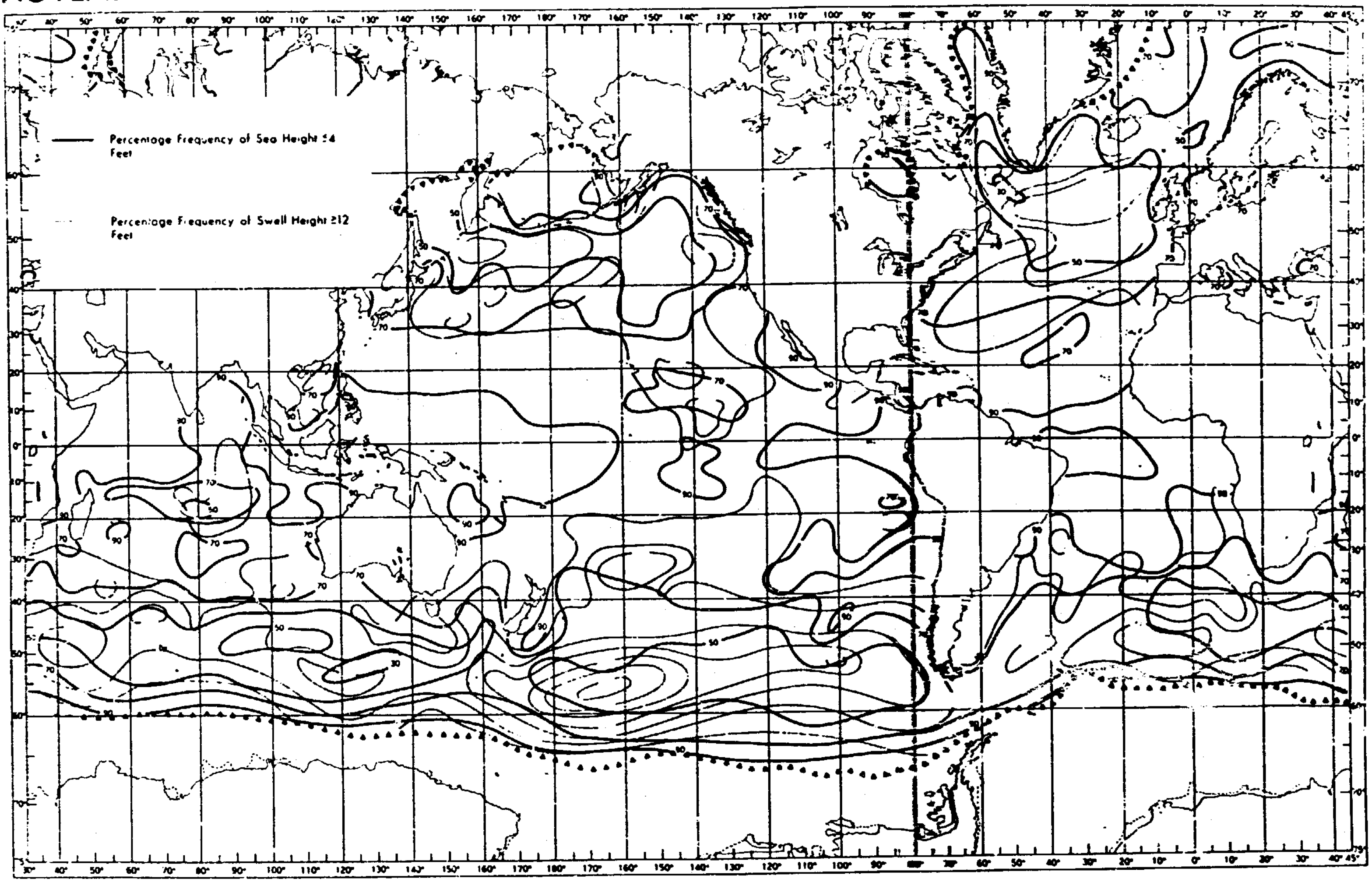


Figure A-8 Worldwide sea and swell - November

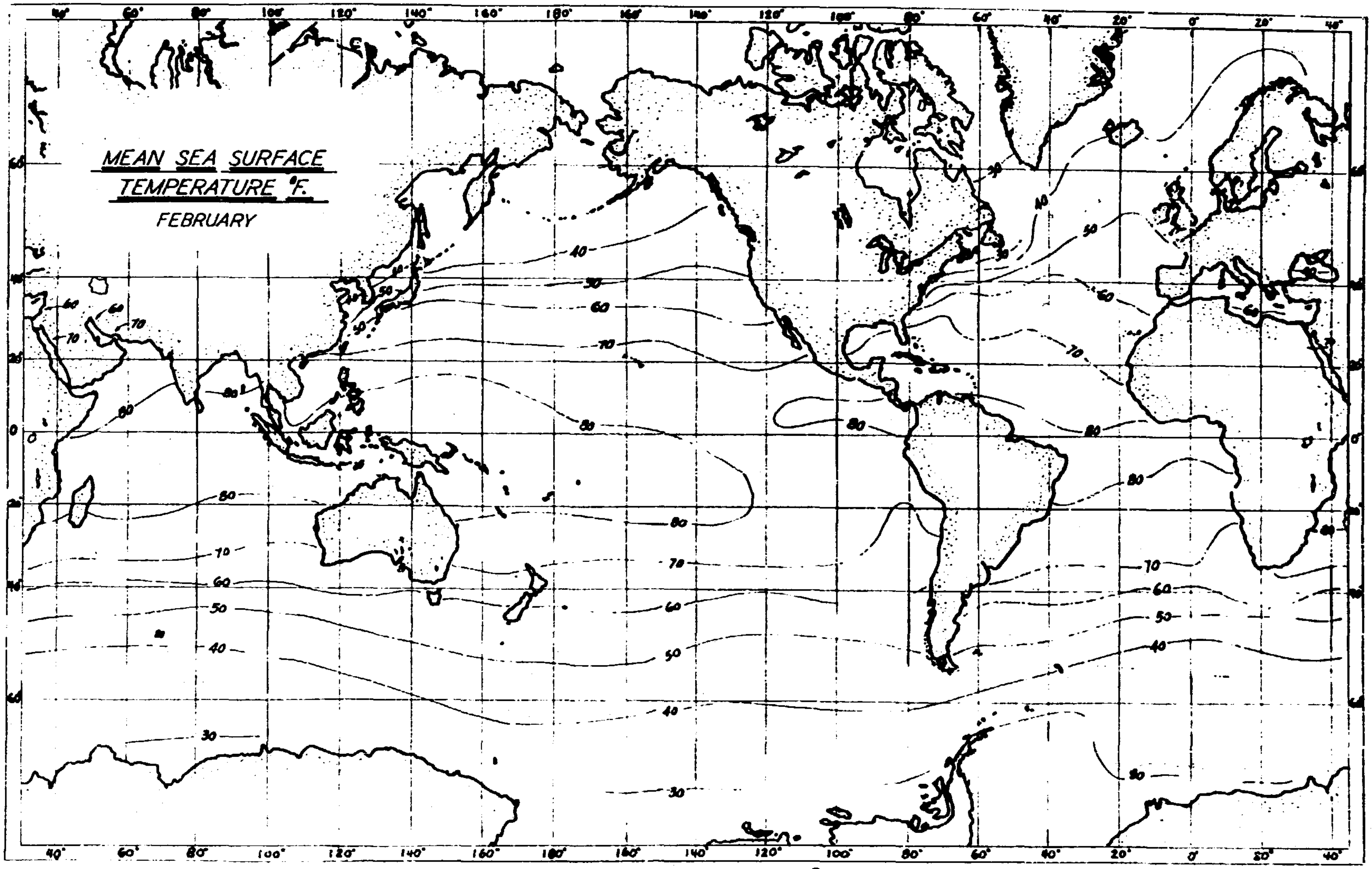


Figure A-9 Mean sea surface temperature °F. - February

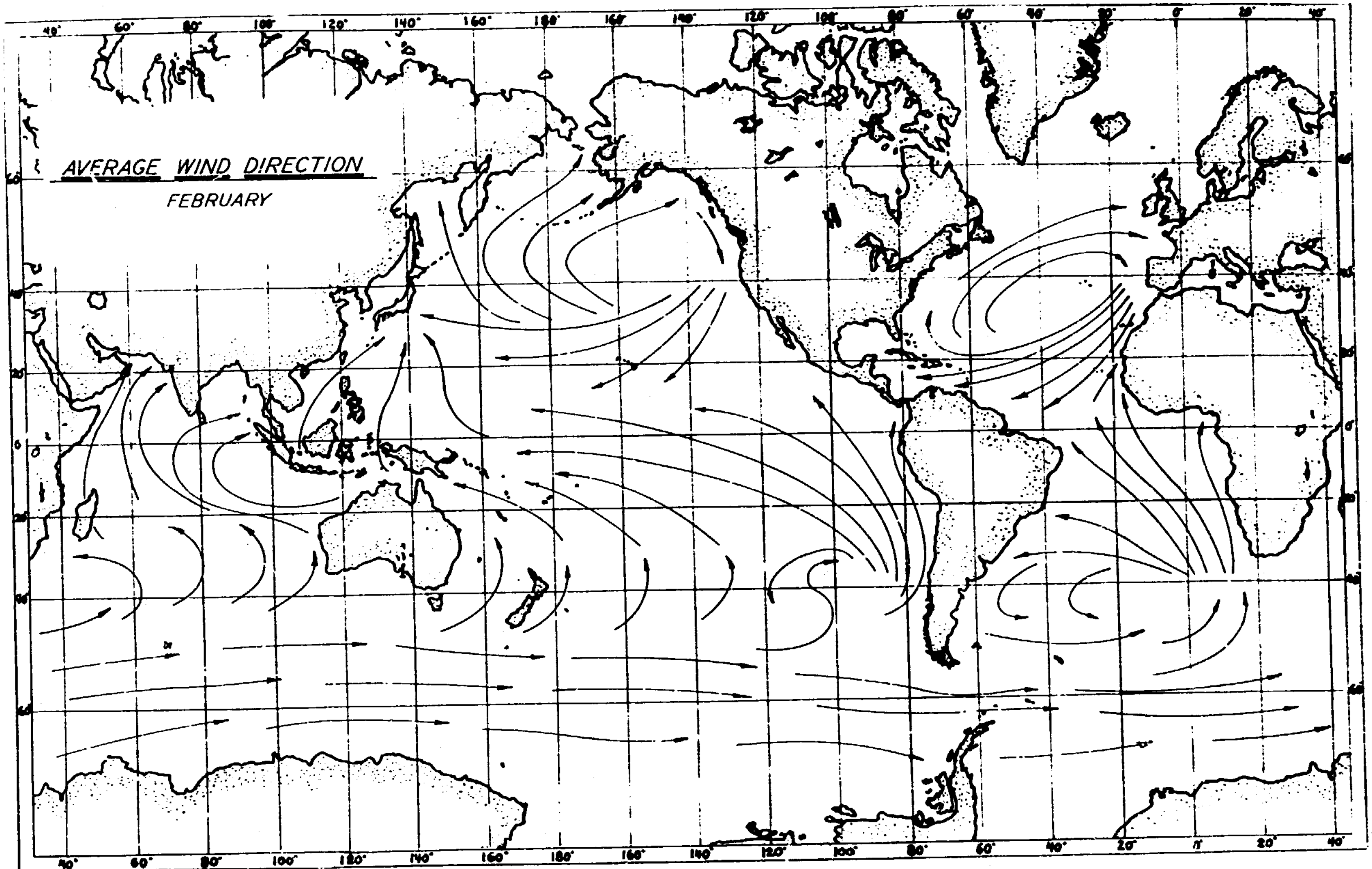


Figure A-10 Average wind direction - February

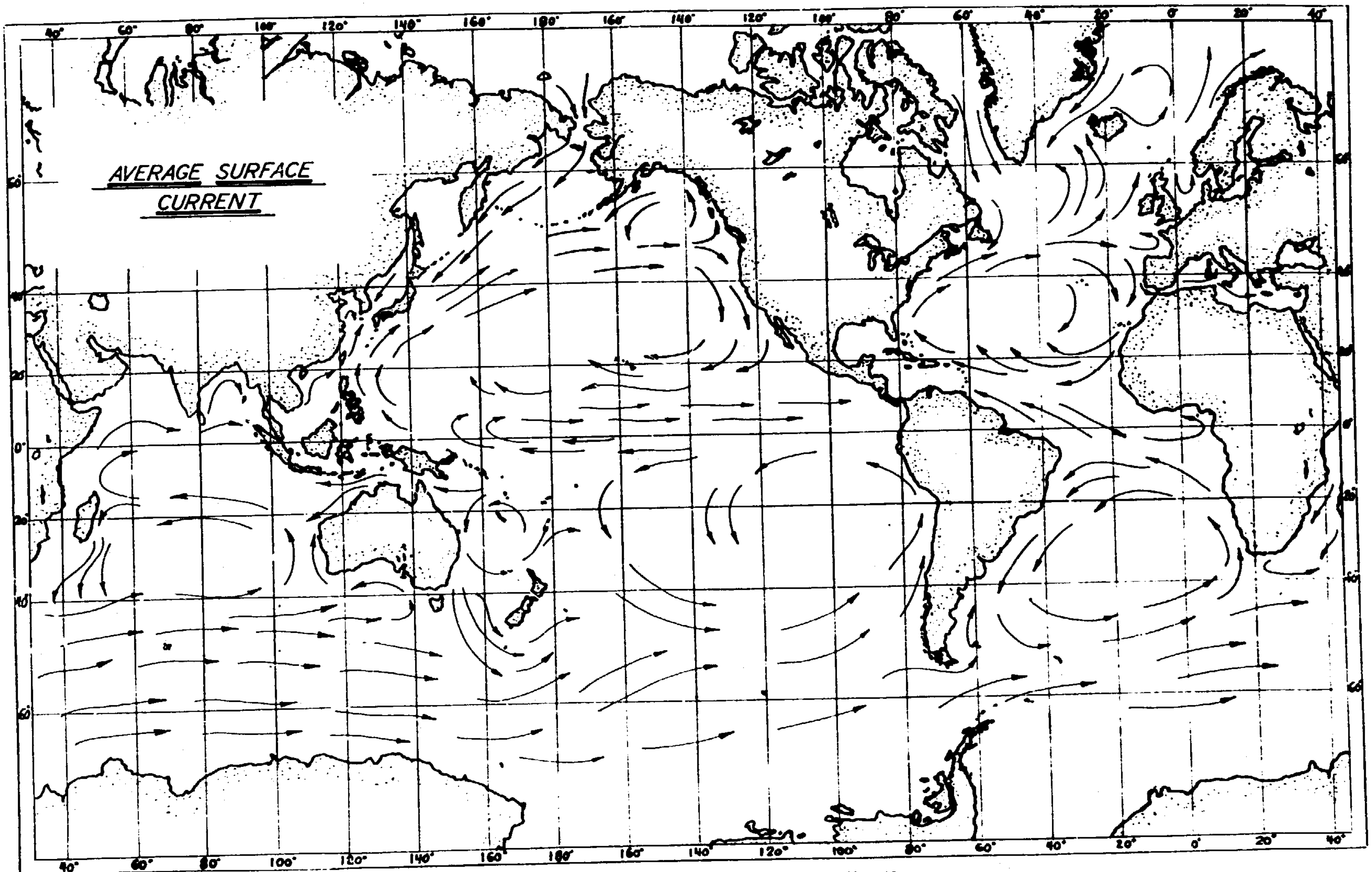


Figure A-11 Average surface current direction

## APPENDIX B

## CASE HISTORIES OF REPRESENTATIVE SPILLS

## APPENDIX B
## CASE HISTORIES OF REPRESENTATIVE SPILLS

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## APPENDIX B

## CASE HISTORIES OF REPRESENTATIVE SPILLS

### 1. The ANNE MILDRED BRØVIG

On February 20, 1966, the Norwegian tanker ANNE MILDRED BRØVIG (24,454 GRT) loaded with 39,000 tons of Iranian crude oil, collided with the British MS PENTLAND (876 GRT) in the North Sea. The tanker caught fire and several explosions occurred. The following day the ship drifted to 54° 22.6' N, 6° 50.0' E, grounded and settled down by her stern in 120 ft of water. The floatable fore-section was cut off on May 2, 1966, and towed to Heligoland and then to Wilhelmshaven. A total of 21,300 tons of oil was offloaded (1,975 tons at the accident scene and 19,325 tons from the fore-end after towing), leaving approximately 17,700 tons discharged into the North Sea or burnt during the tanker fire. Only 2,200 tons could have burned, so that at least 15,500 tons were released to the sea. In spite of the amount of oil which escaped, German beaches did not report much oil pollution. Chemical dispersants (emulsifiers) were used to control the spill at sea. Drifting of the oil was kept under constant observation by planes, vessels, and dead reckoning of the German Hydrographic Institute. It was reported that by calculations, using a drift of 4.2% of the wind velocity and allowing for inshore currents, the time of oil appearing near Blaavands Huk and Fanø was predicted in advance with great precision.(1)

Chemical Dispersion

A total of 19,400 gallons of dispersants were used at sea. The dispersants used were: Moltoclar, Ascal Super 7-11, Slix/Navee, Gamlen, BP-1002 and Ameroid (Drew Chemical). Generally, they were diluted with sea water to the proportion of 1:5 up to 1:20 and sprayed simultaneously, at times, by two or three ships. The dispersing efforts were concentrated on escaping oil in close proximity to the wreck or eliminating "oil streaks", of, at times 1100 yds. long and 5 to 30 yds. wide, starting from the wreck. This prevented the formation of large, integrating oil slicks. Thin oil films more than 0.5 to 0.75 miles from the wreck were not eliminated because of poor results achieved. Pieces of compact oil sludge several inches thick were dispersed quite successfully with undiluted emulsifiers. Complete dissolution of these oil sludge pieces, however, could not be observed.

Only about 3000 to 4000 tons of the total 15,500 to 17,700 tons of escaped oil were treated by emulsifiers. Since no heavy cases of oil pollution were reported, it was concluded that the remainder of the oil dispersed naturally by evaporation, dispersal by emulsification action of the sea water, and biological degradation.(1)

Permanence of the Method - The permanence of dispersion of the ANNE MILDRED BRØVIG oil spills was not established.

Additional Damage by the Treatment - No additional damage was attributed to the use of the chemical dispersants. Samples of the chemicals were tested by the Federal Research Institute for Fishery in Hamburg. The result showed that the toxic limit for sea fish probably was not reached in this case by the use of the emulsifiers in question since these were sprayed by the use of fine nozzles. Also, some of the dispersants are absorbed by the oil and thereby made not harmful to fish. Finally the dispersants are distributed over a

large area by the undulation and currents of the sea. It was concluded that for these reasons, emulsifiers may be applied at sea without endangering the fish resources.[1]

Operational Shortcomings and Limitations - Limitations of dispersants brought out in the ANNE MILDRED BRØVIG experience were that in smooth sea conditions, the application of dispersants must be accompanied by agitation by the vessels, and that had the oil immediately drifted to shore, dispersants could probably not have been applied quickly enough to control the spill. Also, some large oil sludge patches could not be completely dispersed.

## 2. THE TORREY CANYON

### General

The TORREY CANYON, loaded with 118,000 tons of Kuwait crude oil, ran aground on the Seven Stones rocks off the coast of Cornwall, England on March 18, 1967, and released approximately 95,000 tons (26,000,000 gallons) of Kuwait crude oil over a period of about 12 days. The ship eventually broke into several sections and was finally bombed with incendiary devices in an attempt to burn the oil remaining in the ship.[2] The oil released caused widespread contamination of the Cornish Coast of England, the Brittany Coast of France, and the island of Guernsey. Cleanup methods employed by the British and French which included chemical dispersing, sinking, burning and physical removal are discussed below. The British relied largely on chemical treating agents, whereas the French used physical removal methods to avoid damaging shellfish and other marine life with chemicals.[3] Cleanup costs have been unofficially estimated at $8 million to the British Government and $2 to $7 million for the French Government.[4]

### Chemical Dispersing

Approximately 700,000 gallons (3500 tons) of emulsifier-solvent mixtures were used at sea on the TORREY CANYON spill. This was believed to have emulsified at least 15,000 tons of the oil spilt at sea, preventing that amount from reaching the shores.[2]

Permanence of the Method - When spraying and subsequent agitation of the dispersant were correctly carried out, the dispersion was permanent.[2] Whatever the method of detergent application (spraying detergent followed by high pressure hose stream agitation or fire hose streams containing injected detergent) the dispersion was most effective if, after spraying during "dead slow" passage through an oil slick, the vessels returned at speed over the same course providing agitation by the ships propellors.[5] Oil which was completely emulsified in this way dispersed in the sea and subsequently became progressively diluted; where this process was incomplete, however, a variety of water-in-oil and oil-in-water emulsions were formed and in due course driven ashore.[6] However, it is not necessary for detergents to be applied to oil to effect the formation of the oil-in-water type "chocolate mousse" emusion. "Chocolate mousse" similar to that found in Cornwall has been made simply by the agitation of Kuwait crude oil and natural sea water.[5]

Additional Damage by the Treatment - The principal damage from the use of dispersants was to marine life in the intertidal zones at shores where beach cleaning was done. All of the effective dispersants used in the TORREY CANYON spill were toxic to marine and intertidal life, especially shellfish.[2]

Although the damage to intertidal animals and plants was extensive wherever very heavy spraying was done, there was relatively little effect on commercially valuable fish or shellfish.[7] Where removal of oil was done mechanically, the marine life was virtually unaffected; in places where there was heavy use of detergent, the kill of marine life in intertidal zones approached 100%.[6] The toxic agent in the detergent appeared to be the aromatic solvent used in the emulsifier.[8] The types of marine life killed were limpets (almost complete annihilation)[2] molluscs, crustacea, rockpool fish, sea anemones, seaweeds, bivalves, starfish, sea urchens, crabs,[5] lobsters, conger eels, small dabs, flounders and eel elvers.[2] Some clifftop grasslands and grass heaths were killed mainly due to the spill of detergent.[2]

A pertinent conclusion regarding the use of chemicals and toxicity to marine life in open waters is drawn in the report "The TORREY CANYON."[2] That is that the total amount of detergent used at sea during the TORREY CANYON incident would have been diluted to less than one part per million given that it had been dispersed over an area of water 20 miles square down to a depth of 10 feet. At this dilution, detergent is not lethal to mollusks (e.g. cockles) and crustaceans (e.g. lobsters) and probably not to plankton or fish. Other literature[7] [9] draws similar conclusions: i.e. that offshore spraying in deep water has no significant toxic or other deleterious effect on offshore or inshore fishing.

Operational Shortcomings and Limitations - The principal shortcomings and limitations of chemical dispersion were the amount and cost of the chemicals (approximately 700,000 gallons were used at sea[2] costing an estimated $940,000[10]), the toxicity of the chemicals to marine life in the intertidal areas, the large number of vessels needed to apply the chemicals (up to 42 ships) and the inability to apply chemicals fast enough to control the entire spill. Shortcomings of shore use were the tendency of the chemicals to promote sinking of the oil into beaches when used to clean heavily contaminated beaches, and the occurrence of quicksand on beaches treated with chemicals resulting in beach erosion from tidal and wave action. The two latter shortcomings, while serious considerations for oil spill cleanup, are not germane to the subject of treatment of spills on open waters.

## Burning

Burning of the TORREY CANYON cargo was attempted after the ship had broken up. Attempts were made to light small oil slicks believed to be reasonably thick, using "oxygen tiles" (a pyrotechnic device containing sodium chlorate to provide an oxygen-rich flame).[2] [5] These attempts were unsuccessful probably because the highly flammable volatile fraction of the crude oil had already evaporated. Sodium chlorate devices were successful in igniting crude oil exuding from the ships.[2] Bombing of the tanker with 1000-lb. high explosive bombs produced fire in the tanker and in some surrounding patches. Aviation kerosene was jettisoned to feed the fires. Napalm bombs were also used to start fires.[5] Approximately 20,000 tons of oil were estimated to have been burned in the three days bombing.[2] Approximately 160,000 lbs of high explosives, 10,000 gallons of aviation kerosene, 3000 gallons of napalm and several rockets were used in the burning operations.[5]

Permanence of the Method - The oil which burned was permanently removed from the water. No data was obtained on the amount of crude or residue left after it was once ignited. Experiments on fresh crude by the Ministry of Defence burned 1000 gallons of fresh Kuwait Crude one inch deep on a pond using a jet engine to blow air over the pond at wind force six. The oil was consumed in about twenty minutes and the residue was approximately one gallon[5]. However it was recognized that conditions at sea would be different because of loss of volatile fractions by evaporation and spreading of the oil to a thin layer making ignition and maintenance of combustion difficult. Burning of "chocolate mousse," which contains 70 to 80% water, was attempted in pools on the shore. "Oxygen tiles", magnesium powder, flame throwers, and flame-thrower fuel were used but burning ceased as soon as the added fuel was exhausted or the flame thrower removed.

Additional Damage by the Treatment - No damage to marine life was reported from burning oil. The ship itself was damaged by the bombing and fires but had already broken up and been abandoned. Damage to other ships was avoided by clearing the area.

Operational Shortcomings and Limitations - Shortcomings and limitations of the burning methods used in the TORREY CANYON spill were the high cost of the planes, explosives and fuels; the inability to burn thin slicks, weathered crude, and "chocolate mousse", and the loss of visibility from flame and smoke during burning operations.

Sinking.

Little data is available on the sinking methods used on the TORREY CANYON spill. All sinking was done by the French. It was reported that powdered chalk treated with stearic acid as anti-wetting agent, was successful in absorbing and sinking oil emulsion in the Bay of Biscay.[2] [6] Some 3,000 tons of the material were reportedly used to sink about 20,000 tons of oil. Although good data is generally lacking as to the amount of oil actually treated, the oils were reported sunk in 60-70 fathoms and coastal pollution was minimized. The French success was attributed to good spreading and mixing of the chalk into the oil body and the high density of the weathered slick, thereby requiring considerably less absorbent as compared to fresher oils.[11] Minesweepers and fishing boats were used to apply the treated chalk.[12]

Permanence of the Method - It is reported that 14 months after the incident, no sign of oil was found over the water surface where the oil was sunk.[11] The permanence of this procedure may not be apparent for some time.[6]

Additional Damage by the Treatment - Additional damage by sinking is not well established by TORREY CANYON experience. The British refrained from the use of sinking to avoid contamination of fishing grounds around the British coasts and because of the possibility of fouling of nets and fishing gear dragged along the sea bed.[2] A trial by the Warren Spring Laboratory on oil sunk by treated sand resulted in the recovery of some of the sunken oil by trawling. The fouling of the gear was sufficient to require the net to be cleaned or changed, and the fouling of certain fish, such as the rough-skinned dog-fish was found to be greater than had been expected. The trials demonstrated also that the sinking of oil under open sea conditions was much less efficient than had been indicated by the laboratory tests and, moreover, that oil which has been treated but not sunk appeared to be much more resistant to treatment either with a further slurry or with a dispersing chemical.[13]

Operational Shortcomings and Limitations - The broadcasting of a finely divided material such as chalk under windy conditions has been reported to be difficult and is one limitation of the sinking method. One report[14] states that the French experienced considerable difficulties. Other shortcomings and limitations are the logistics of transporting the quantities of material needed to sink the oil (3:1 to 1:1 agent to oil by weight), inability to sink distillate fuels, and restrictions as to location of sinking (e.g. not over commercial fishing grounds). Little data on the above named items are available from the TORREY CANYON experience.

Mechanical Removal - Skimming and Absorption-Collection

Physical removal of oil from the water surface by the British was confined to the use of straw in estuaries near booms. Their conclusions were that no mechanical equipment was available that could be used in waves exceeding about six inches or so or had sufficient capacity to cope with a spill of the magnitude involved. The French did try using both sawdust and polythene foam. Collection proved impossible and the agglomerated particles were eventually deposited on the shores of Brittany[2]. Some success with mechanical removal of five-week old "chocolate mousse" by the French was reported.[2,8,9,15] A 3000-ton coastal tanker the PETROBOURG, was equipped with floating booms and positioned, broadside, immediately downwind of the oil. The "mousse" collected to a depth of 2 ft against the side of the ship and was sucked up from floating wiers into the cargo holds using the ship's own pumps. The arrangement had capability of removing 1500 tons of oil or emulsion daily. Some 1200 tons of emulsion were collected in two days in relatively calm waters (two to four foot waves).

Permanence of the Methods - Removal of oil mechanically into ship's holds provided permanent removal. Absorption methods would have provided permanent removal had they incorporated equipment for harvesting at sea. However such equipment was not available; hence the material eventually floated to shore, requiring shore cleanup.

Additional Damage by the Treatment - Mechanical removal directly to ships holds produced no additional damage. Absorption methods (sawdust, polythene) which later came ashore, while not effective, were not cited as causing additional damage.

Operational Shortcomings and Limitations - Mechanical removal by pumping into ships' holds was limited to thick patches (6 inches to 1 foot thick) of emulsified oil or "mousse", and to sea conditions where a ship could be positioned and operated broadside to the wind (admittedly, booms on the ship's bow would increase the maneuverability and stability of the system, but this was not done). Capacity, using one vessel, was limited to the ship's holds capacity, requiring return to port before resuming operations. The mechanical removal system used would be relatively ineffective on thin films. Absorption methods used, where no mechanical pickup was provided, were ineffective.

Booms

While the use of booms is not a method of removing or dispersing oil, booms are often used as a mechanical part of such processes. Twenty-three booms were in position by April 1, to protect harbors, estuaries and beaches from the TORREY CANYON oil. Some were

improvised and some were commercial equipment. Several booms, both improvised and purpose-built, installed at the Porthleven Harbor entrance failed to hold back oil and broke up in rough seas.[5] With any sea running, they either rode over the oil because of inadequate skirt depth, or the sea and oil broke over them because of inadequate freeboard. A boom imported from the U.S., used at St. Ives and along beaches was ineffective not only because it occasionally parted, but its six-inch freeboard was virtually useless in the face of the open sea.[5] Experience gained in Cornwall is that existing booms cannot be considered effective if exposed to currents of over 2 knots or waves of a foot or so in height.[5] A freeboard of 4 to 6 ft, a 4 to 6 ft skirt, rugged construction and little maintenance requirements were suggested as prerequisites for a boom to have a reasonable chance of success under conditions such as exist around Cornwall.[5] Smith reported that the largest boom generally in use was about 18 inches in diameter with a weighted skirt hanging down some 3 feet and that anything more than a 1 to 2 knot current and waves higher than about 6 inches will remove oil from a boom of this type.[16]

A boom of polyurethane blocks each 30 ft long, 3 ft 6 in. wide and 3 feet deep, wrapped in fishing net, joined together with hawsers and a canvas skirting four feet deep weighted with chains was built for the purpose of encircling the wreck.[2,16,17] The boom floated 3 feet out of the water. The vessel broke up before it could be used there and the boom was installed across one of the river estuaries under much less severe conditions of wind and sea where the anchorage broke and the boom disintegrated.[16]

It was reported that the Warne boom (16 inch diameter floatation cylinder, 22-inch skirt) was the most satisfactory commercial boom and that it excluded oil from Porthleven Harbor in spite of a seven foot swell, until the boom broke.[2]

## 3. THE OCEAN EAGLE

### General

The 12,065 ton tanker OCEAN EAGLE, carrying 5,700,000 gallons of Leona crude oil, grounded at the entrance to San Juan Harbor, San Juan, Puerto Rico, on March 3, 1968. The ship broke into two parts about two hours after grounding. Approximately 3 million gallons of oil escaped from the ship; the remainder was offloaded into barges. The two parts of the ship were removed from the harbor and sunk in early April in 600 fathoms of water about 8 to 10 miles north-northwest off El Morro. About 2 million gallons of the spilled oil spread throughout the harbor and the remainder drifted offshore as far as 30 miles east and 40 miles west due to unusual weather conditions. Slicks were reported up to a distance of 10 miles offshore.[18] Some of these offshore slicks drifted back later and recontaminated beaches. Unofficial estimates of cleanup and salvage costs totaled $2 million.[4]

Damage from the oil was to sea birds (primarily pelicans), holiday beaches outside the harbor, harbor structures and beaches, fishing boats and equipment, and small craft. Most of the recovery or treatment operations were in the harbor or on beaches. Some at-sea treatment was done and this is described in the following:

## Chemical Dispersing

Chemical dispersing was performed to break slicks offshore over a period of four days before this procedure was discontinued (except where required to reduce the possibility of fire, or reduce its intensity should one occur around piers and wharves). The reasons for its discontinuance were given as: the use of detergents harmed marine life, coagulated the petroleum into heavy balls which sank to the bottom in the near shore, and formed a quicksand condition in the beaches.[18] Tugboats and helicopters were used to spread the chemicals. In general they were applied on the inshore edges of the oil slicks in an effort to prevent spoilage of the beaches.[4]

Oil in flats and backwaters built up to several inches thick, and due to the continuing loss of volatiles became tarry and most resistant to emulsification.[4]

Permanence of the Method - The permanence of chemical dispersing was not established at the OCEAN EAGLE spill. Some field tests were conducted by the U.S. Coast Guard but the results were reported as inconclusive although each dispersant tested seemed to work reasonably well.[4] Helicopter application of dispersant was reported to be quite successful in controlling the spread of oil from the stern section by spraying the freshly leaked oil and agitating the emulsifier with the rotor wash.[4]

Additional Damage by the Treatment - Some mortality of marine life occurred as a result of the OCEAN EAGLE spill but the amount attributed to the oil, the detergents, or some other factor (such as fungus or bacteria) were not determined. In particular, 95% of a 100,000 fish school of arenque, sardina (Opisthonema oglinum), the prime bait fish used by fishermen in the area, was noted to be seriously affected by lesions. Other damage noted was the tendency of the emulsifiers to make beach sand quick. It was also noted that oil which had been treated with emulsifiers was more difficult to remove from beaches than the pure crude.[4]

Operational Shortcomings and Limitations - Toxicity of the available dispersants to marine life at levels above 1 ppm for sea-urchins, and above 5 to 10 ppm for fishes such as silversides, moharra, herring and sergeant major fish,[19] was sufficient reason for the Puerto Rican authorities to discontinue their use. Other shortcomings cited were the promotion of quicksand in beaches, difficulty of removal of treated oil from beaches, and the high cost. Also the use of dispersants was limited to daylight hours because of navigational hazards and because the heavier slicks could not be identified at night.

## Mechanical Removal - Skimming and Absorption-Collection

Removal of the oil from San Juan Harbor was most successfully done by vacuum trucks and an 8000 barrel barge equipped with vacuum pumps; these operations recovered 45,000 gallons of oil per day.[4,18] Use of a catamaran type power boat with an absorbent drum and squeeze roller was limited to the bay where a calm sea prevailed.[18] It was reported that it did not perform well in the debris-chocked waters of the harbor and its use was discontinued.[4] Neither of these mechanical methods was used on open waters.

Several absorbents were used on the offshore slicks and included sugar cane bagasse, treated perlite (Ekoperl), treated vermiculite (puramar), and treated talc (Mistron Vapor).

The bagasse was found to be ineffective. Other absorbents, of which Ekoperl was the most widely used because it was available first, were applied to offshore slicks by helicopter or small power boats. The process of collection in the sea was difficult; therefore the mixture was allowed to float to the shores where mechanical collection was feasible.[18] The most effective method of application, which was reported as exceedingly expensive, was by helicopter where the slicks could be easily located and rapidly treated. The prop-wash mixed the powder with the oil. About 50 sacks of Ekoperl were applied in less than 20 minutes during each flight. Boat application was tedious because of difficulty of locating slicks and rough wave action.[18] Where small power boats applied absorbents on slicks along the coast, the absorbent was allowed to float to shore and collected manually with wire mesh baskets and ropes.[18]

One reportedly successful application of 126 sacks (4 cu. ft. or 24 lbs per sack) of Ekoperl was made from a boat to a slick 2.5 miles offshore. The slick was approximately 2 miles long by 300 to 500 ft wide. It was described as fairly well concentrated, very thick and very heavy viscosity, not emulsified. Wave action (4 to 6 ft waves) spread and mixed the absorbent and it apparently cleaned up the area thoroughly, where applied. The light colored dust turned dark brown as it absorbed the oil. A thin opalescent film remained. It was reported that more absorbent, a total of 300-350 sacks would have effectively treated the slick.[19] It was not reported where the floating absorbent eventually beached, or if it did.

Permanence of the Method - Removal of oil mechanically into tank trucks and barges provided permanent removal. Absorption methods did not remove oil from the water surface because collection at sea was not done. The material which floated to shore was subsequently picked up in accessible areas. The time lapse between application and collection sometimes permitted the heating action of the sun and wave action to separate the crude from the absorbent before collection was possible.[18]

Additional Damage by the Treatment - Mechanical removal of oil to tanks produced no additional damage. Absorption by perlite and similar absorbents was not cited as causing additional damage. Toxicity tests on the absorbents by the University of Puerto Rico, showed no ill effects to chitons, limpets and sea urchins when absorbents were floated on the surface, ground up and dispersed in the water and when sea urchins and limpets were rolled in powdered absorbents and returned to the water. Tests of Ekoperl at 500 ppm showed no mortality in 24 hours of sergeant major fish and 10% mortality at 12 hours of moharra fish. A test of Mistron Vapor, showed 100% mortality of moharra fish after 6 hours at 1000 ppm.[19] That material was used primarily on beaches.

Operational Shortcomings and Limitations - The use of mechanical removal by vacuum equipment was limited to the relatively calm waters of the harbor where thick layers of oil existed. These operations were hampered by intermittent stoppages due to accumulated debris. The drum skimmer was also limited to calm waters and was rendered ineffective by debris.[4] For the absorption method, there were several shortcomings and limitations as follows:

1. The material could not be collected at sea; therefore it was allowed to come ashore for collection; sometimes the material beached on inaccessible shores.
2. Where absorbents did come ashore, heat and wave action caused them to lose the oil unless collected soon after beaching.

3. Laboratory tests by the University of Puerto Rico indicated that sugarcane bagasse, vermiculite, and chemically treated vermiculite had no absorbency, competed with the oil for surface and spread it more, and leached all the oil when exposed to the sun and weather for 24 hours.[19]
4. One report stated that the Ekoperl, Mistron Vapor and Puramar proved very useful on the beaches where they provided sufficient body to facilitate its physical removal but that there was little evidence to support the value of their use on open water.[4]
5. Application, with available equipment, was difficult and dust was a problem. The use of goggles and masks were necessary when applying Ekoperl to prevent irritation of eyes and throat. The powders were inhaled by helicopter radiators if applied with the wind or in a stationary position. The powders were therefore spread while flying into the wind.[18]
6. Dust from the absorbents obscured vision. The MRV CARITE ran hard aground while spreading perlite due to dust obsuring vision.[20]
7. A close-by base of operations was a prerequisite for effective use of a helicopter.[18]

### Booms

A small (reported as 8-inch[4] or 12-inch[18]), plastic boom was used in an attempt to confine the oil around the stern of the ship but proved ineffective due to strong wave action and fragile construction.[18] Oil escaped over and under this boom.[18] A wooden barrier was used to block oil from entering Condado lagoon which connects with San Juan Harbor. Rough wave action destroyed the barrier and it was rebuilt several times and was finally allowed to float freely on the water to offer less resistance to the waves. The barrier and boom were reported to be effective, and floating wooden booms were subsequently used in protected embayment such as the Caribe Hilton beach and the San Geronimo beach. These booms were also set free by the rough wave action and had to be reconstructed.[18

## 4. THE GENERAL COLOCOTRONIS

### General

The GENERAL COLOCOTRONIS, carrying 18,000 tons of Bunker C fuel oil, grounded on a coral reef about one mile off Eleuthera Island, Bahamas, on March 7, 1968, spilling about 2,600 tons of oil. The remainder of the cargo was off-loaded to another ship, the ESSO MARGARITA. Chemical dispersing was used to treat oil on the sea. Little damage occured from this spill. About 3 to 4 miles of undeveloped beach and inaccessible shore were polluted out of some 2,000 to 3,000 miles of holiday beaches which might have been affected by a heavier spill or unfavorable winds.[21]

### Chemical Dispersing

Three chemical dispersants were reported used on the oil spill; Enjay Corexit 7664, Magnus Oil Spill Disperser and Ameroid Oil Spill Disperser No. 1 (Drew Chemical). These chemicals were applied near the wreck and in the shallows by vessels such as a landing craft

(LTI) equipped with a Bahamian Fire Service Pump and drums of dispersant, and a raft for spraying operations close to shore. Small quantities were used, followed by efficient mixing to minimize toxic effect.[21]

It was reported that the Enjay and Magnus products worked very well on the thin slicks of Bunker C oil soon after it had escaped from the tanker[21]. Observations of the effectiveness of other dispersants used were not reported.

To avoid the problems of toxicity, quicksand, and sinking of oil into the sand, cleaning of beaches with detergents was not done. Instead the oil was left to be cleaned by chitons and limpets, bacterial action, and other natural processes such as burial or removal by hurricanes.[21]

Some dispersants were used on oil near the beach, spraying them into oil while still on the water, close in shore from a small boat or using the pump on shore and spraying into the breakers, using sea water.

Permanence of the Method - Indications of the permanence of the method are 1) the report that the dispersants worked very well on the thin slicks of Bunker C oil, 2) that they were efficiently mixed (which would materially assist in achieving a permanent dispersion) and 3) the fact that minimal oiling of beaches occurred from this spill.

Additional Damage by the Treatment - No additional damage was attributed to the use of dispersants. Such small quantities were used, followed by efficient mixing, that no toxic effect could have resulted.[21] Very preliminary and rough toxicity tests were conducted on Corexit 7664 (water based), the Magnus, and Drew products (solvent based) and on Polycomplex A-11, another water-based dispersant. These tests showed that Corexit 7664 was non-toxic at 100 ppm and 1000 ppm to small fishes (Abudefduf saxalilis) small gastropods (Zebra Nerites), small spider crabs and other crabs, tiny bivalves, sea urchins and chitons. The Magnus product was reported as having a toxicity level of about 10 ppm, with the Drew product probably somewhat more, and Polycomplex A-11 somewhat less toxic to the series of marine animals tested.[21]

Operation Shortcomings and Limitations - Minimal shortcomings were reported in the use of dispersants on the GENERAL COLOCOTRONIS spill. The dispersants with a solvent (volatile kerosene) base are liable to be injurious to the skin, eyes and air passages of personnel applying them, and under tropical conditions protective clothing was impracticable.[21] The non-injurious (water-based) types cost more per gallon than the solvent-based types.

Booms

A boom was installed at the north end of French Leave beach stretching across to an islet. The freeboard was about 6 inches and consisted of solid polystyrene cylinders strung closely end to end, with a skirt of heavy plastic about 18 inches deep. Boom sections were about 8 feet long and it was moored with steel cable. The jagged coral rock necessitated repeated maintenance. It was reported that the boom was considered to be chiefly of psychological value as it could not have held back thick oil.[21]

5. THE ESSO ESSEN

General

The German tanker ESSO ESSEN (48,535 dwt.), carrying Arabian heavy oil from the Persian Gulf, struck a submerged object on April 29, 1968 about 3 miles off the South African coast near Cape Town. It steamed from 5 to 12 miles off the coast and then was ordered out to sea on the same day to drift 80 miles offshore. About 15,000 tons of oil were lost of which an estimated 3,000 to 4,000 tons were spilled off the coast. Chemical dispersing was used and several miles of the coast were contaminated by oil floating to shore. The principal damage from the oil was the oiling of shores, death of sea birds and sand hoppers.(22)

Chemical Dispersing

The dispersant used was Corexit, flown to Cape Town from the U.S. This material was claimed to have been tested extensively and to have shown no ill effects on sensitive organisms such as shrimps at concentrations of 10,000 ppm. The spraying of oil on the sea was commenced on May 3 with the aid of four light aircraft which flew for about 30 hours and used 75 drums of dispersant up to May 6. The aircraft concentrated on the area between Hout Bay and a point 15 miles south of it, spraying from the beach to three miles offshore.(22)

Permanence of the Method - It was not possible to assess how fruitful the spraying of Corexit had been. When operations were started, an estimated 80 to 90 percent of the oil had been beached, and the remainder was highly dispersed due to wind and wave action. In a laboratory test, 2 cc of Corexit, 2 cc of crude oil and 96 cc of sea water was shaken vigorously for 10 seconds. Corexit frothed very markedly during mixing and after 15 minutes there was still a thin, frothy layer at the surface with a thin layer of oil globules below it; the water below the latter was almost completely clear. Within a few hours, the oil at the surface seemed to have consolidated again.(22)

Additional Damage by the Treatment - Although considerable numbers of dead zooplankton were noted during plankton surveys at depths of 0 to 2 meters in and around the area treated with Corexit dispersant, these mortalities were attributed to natural causes, namely a sharp temperature transition from a warm water upwelling. It was reported that spraying with dispersant was not responsible for the zooplankton mortalities.(22)

Short term toxicity testing was done with Corexit which established that it was considerably less toxic than previously used dispersants, e.g. one of the least toxic compounds used in the TORREY CANYON cleanup killed rock fish (Clinidae) in less than one hour at 500 ppm whereas they survived 24 hours in Corexit at 500 ppm. In the tests, periwinkles and whelks survived 24 hours at 10,000 ppm of Corexit; starfish survived 24 hours at 500 to 1000 ppm; abalone survived 24 hours at 10 ppm with no ill effects, were seriously affected at 500 ppm and died in 16 hours at 10,000 ppm; small rock lobsters were unaffected after 24hours at 10 ppm, showed no marked effects in 24 hours at 500 ppm, and showed 100% mortality after 20 hours at 10,000 ppm.(22)

Underwater surveys in the area which was most severely polluted and probably received the heaviest dosage of dispersant showed no destruction of flora or funa. Cores taken at various places showed little penetration of the oil into the sand.[22]

Operational Shortcomings and Limitations - Although no particular shortcomings or limitations for the aerial application dispersant were cited in the literature, some can be deduced from the experience here and in other locations. Aerial application would require a base of operations reasonably close by, and tolerable flying weather. Lack of physical agitation of the dispersant could be expected to lessen its emulsifying efficiency and cause more dispersant to be used. Application to a large spill quickly enough to prevent beaching would require large numbers of aircraft and large quantities of dispersant on hand. For example, treatment of 4000 tons (approx. 1,100,000 gallons) of crude oil at a dosage rate of 1:10 agent to oil by volume, would require 110,000 gallons of dispersant to be applied in a matter of a day or so. (The first oil from the ESSO ESSEN grounded about one day after the accident.) If a plane dispersed 1000 gallons in 30 hours, it would require 110 planes to spread 110,000 gallons. The cost of the dispersant, alone, F.O.B., the factory, would be approximately $390,000 (3.55/gal. x 110,000 gallons).

## 6. THE SANTA BARBARA CHANNEL INCIDENT

On January 28, 1969 Union Oil Company well A-21 on Offshore drilling platform A in the Santa Barbara Channel blew out and a leak of mixed gas and crude oil occurred.

The released crude oil was driven ashore by south-easterly winds, resulting in contamination of beaches, harbors and rocky coastline, and initiating perhaps the largest oil cleanup operation that has occurred in the United States. Estimates of the rate of release at any one time varied considerably and it was impossible to measure the flow rate or cumulative volume[23]. Allen[24] estimated the cumulative total was 77,000 barrels after 100 days. This is equivalent to about 12,000 tons.

The principal damage from the oil spill was contamination of beaches and rocky shores, piling, wharves and ships in harbors and to birds. Total known bird losses through March 31 in the area affected were determined to be 3600.[23] Marine mammals such as sea lions, seals, and whales were not affected adversely by the oil. Nor were there any serious acute kills among intertidal species, as determined by general ecological surveys and independent observations by biologists.[23] Cleanup methods used or experimented with on the sea in the Santa Barbara incident included chemical dispersants, absorbents, skimmers, and booms which are discussed below.

### Chemical Dispersing

Chemical dispersants were applied at sea for two purposes: (1) to prevent the oil slicks from reaching the shore as they approached the beaches and (2) to reduce the hazardous concentrations of flammable oil in the immediate vicinity of the platform. Application of chemical dispersants was discontinued in all areas, other than the immediate vicinity of the platform (within one mile) for safety reasons, when the FWPCA advised that the chemical usage had exceeded the manufacturer's recommended application ratio based on the Union Oil Company estimate of 2500 barrels of oil released[25]. Approximately 37,500 gallons of

dispersants were applied by spraying from surface vessels at $30-$40/hr. supplemented by "mixer" ships renting for $20-40/hr. Two fixed wing aircraft were also used for spraying dispersants at an estimated cost of $30-$40/hr. Dispersant costs varied from about $2.50 to $5/gallon.(23) At the platform, a total of 1275 gallons of dispersant was injected underwater near the emission points on the seafloor to reduce the fire hazard of the oil as it emerged on the water surface.(23)

Permanence of the Method - Experience at the Santa Barbara incident did not establish permanence of chemical dispersing. When applied properly, the dispersants were effective in removing the slick from the water surface. Little or no quantitative information is available pertaining to the long term effectiveness, based on continuous visual observations of a particular area, of the dispersants used in the Santa Barbara Channel.(23)

A qualitative test of Corexit 7664 and Polycomplex A-11 to disperse the crude oil on seawater was conducted February 9, 1969 near Platform A. It was concluded that the dispersants tested were not significantly better than the mechanical energy supplied by a boat's propellors when attempting to break up an oil slick in open sea.(23) (26)

Other tests concluded that ARA Gold Crew Bilge Cleaner has the ability to disperse the type of oil being lost at Platform A in concentrations as low as four gallons of chemical per barrel of oil, provided the oil is relatively nonweathered and the chemical is applied with a great deal of agitation. Later tests on heavily weathered oil proved completely ineffective.(23) (26)

Additional Damage by the Treatment - Chemical dispersing was not cited as causing additional damage in the Santa Barbara incident. Precautions were taken to prevent damage, based on experience gained in other oil spills. These precautions included: (1) Chemical dispersants were not employed on beaches due to potential for driving oil deeper into the sand and producing "quicksand" condition; (2) dispersants were generally not applied closer than one and one-half miles from shore to minimize toxicity to nearshore marine life, and (3) where possible, the rate of application of dispersants was limited so as not to exceed a concentration of 5 ppm in the top three feet of the water column.(23) The latter two precautions are recommendations of the FWQA concerning the use of chemical dispersants in such situations.(23) (27)

Static bioassay tests were performed by the Union Oil Company on seven dispersants using the procedures of the Standard Methods for the Examination of Water and Wastewater, Twelfth Edition, (1965). The 96-hour $TL_m$ results on test fish, Fundulus Parvipinnis were:

| Sufactant | 96-Hr. $TL_m$ in ppm |
|---|---|
| Ara Bilge Cleaner | 128 |
| Corexit 7664 | 7,200 |
| Crain OD-2 | 118 |
| H-4000 | 81 |
| Polycomplex A-11 | 134 |
| Surfemul #5 | 350 |
| Unico | 220 |

Operational Shortcomings and Limitations - Reference 23 noted the following shortcomings and limitations of chemical dispersing:

"The effectiveness of chemical dispersant is considered questionable for use on large spills and despite their use at Santa Barbara, oil was deposited on the shore line. However, all persons contacted generally agreed on the following:

1. Chemical treatment of large oil spills is extremely costly.
2. The distribution logistics problem is formidable.
3. Natural agitation is not always adequate for full chemical effectiveness.
4. Effectiveness is greater on thin rather than thick films.
5. Permanence of dispersion under field conditions is doubtful.
6. Information on toxicity to marine organisms is sketchy.

Other limitations were that some of the dispersants tested appeared ineffective on heavily weathered Santa Barbara crude oil.

Mechanical Removal - Absorption-Collection

Straw and other commercial sorbents were spread over the oil slick in the vicinity of the platform and near shore. Straw, because of its ready availability, low cost, and relative ease of pickup, was the only sorbent subsequently used on a large scale. It was found to repel water and absorb 4 to 5 times its weight in oil.(23)

Two types of straw were used–Bermuda straw and the more common straw from wheat stalks. Bermuda straw, closely resembling hay, is much finer than common straw and, like hay, was found less effective because it absorbed a much smaller volume of oil.(23)

Power mulchers of the type used to spread straw along highway borders to prevent erosion were used to distribute the straw both on beaches and at sea from workboats. Up to 45 tons per day were spread near the platform in late February by two ships.(28) Up to 140 tons per day were spread by vessels working parallel to the beach a few hundred yards offshore.(29) Individual mulchers were capable of broadcasting 8 to 10 tons of straw per hour.(26)

At-sea recovery of the oil-straw mixture was considered but no information could be found regarding mechanical methods tested at sea to recover the agglomerated mixture from the surface and no device is known to have been used to recover the mixture at sea. Manual pickup in shallow water and after straw washed up on the beach was generally practiced.(23)

The cost of straw varied from $24 to $35/ton. Estimates of total straw used varied from 3000 to 7000 tons.(23)

Other sorbents applied at sea included perlite (Ekoperl), micronized talc (United Sierra Talc - Mistron Vapor) and foam pads. Limited amounts of the perlite and talc were tried but their use was discontinued due to cost and difficulty in subsequent pickup.(23) Limited field testing was done on Scott Industrial Foam, but the materials were not used for cleanup purposes. The tests indicated the particular formulation tested did not absorb enough oil to be practical for large oil spills. On a second test where a slab of foam was moved through the water it was observed that the water was passing freely through the foam while the oil remained on the upstream surface of the foam. While the method appeared successful and promising it was not used because it was not a finished product ready for use.(26)

Permanence of the Method - The use of sorbents on the open sea did not provide removal of oil from the water surface because collection at sea was not done. The material required pickup on shore to complete the removal process. Once this was accomplished, the removal was permanent.

Additional Damage by the Treatment - No additional damage was attributed to the use of sorbents in the Santa Barbara Channel incident.

Operational Shortcomings and Limitations - Sorbents such as straw applied at sea near the platform were of doubtful effectiveness as the straw-oil mixture was not easily recovered and tended to clog skimmers designed for removing oil. Perlite and talc were applied in limited amounts but their use was discontinued due to cost and difficulty in subsequent pickup.(23) The shore pickup of the sorbents, primarily straw, was a costly and laborious process even though mechanical equipment, straw blowers, bull dozers, loaders, graders, trucks, etc. were used. Estimates(26) indicate that the clean up effort peaked at almost 1,000 men and 125 pieces of mechanical equipment. Manual effort was required on inaccessible beaches. Another shortcoming was the need to locate suitable areas for disposal and to dispose of the oil-soaked straw. Up to June 1, 1969, 9826 loads of oil soaked straw and debris had been disposed of.(26)

Mechanical Removal - Skimmers

Some success with skimming devices was reported in the Santa Barbara Channel incident. Most persons contacted in the review of the incident(23) agreed that mechanical recovery was preferable, if possible on the open sea.

As in other major spills in or near a harbor, the greatest success with mechanical removal was achieved in stilled harbor waters. Recovery of the majority of the accumulated oil in Santa Barbara Harbor was accomplished by vacuum tank trucks followed by manual spreading and pickup of straw.(23)

At sea several devices were employed. Offshore workboats equipped with suction pumps were effective in removing thick oil layers accumulated on the surface and behind booms when the oil was several inches thick. The MV PIKE I was reported to have skimmed 250 barrels of an oil-water mixture (ratio unspecified) on 3 February.(30) Later in February, MV WINN was fitted with a Union Oil-designed skimming device consisting of a square box or chamber approximately seven feet on each side. Buoyancy was provided by empty 55 gallon drums on the corners. An overflow weir was mounted in the center of the box from which the oil-water mixture was pumped through the bottom of the weir to storage tanks on the ship. A curved boom was used in conjunction with this skimmer to collect the oil. Operational problems were encountered when it was advanced through the water (too much water recovered), and straw reportedly plugged the intake. However, the device achieved some success when the oil was sufficiently concentrated. On 28 February, off-loading of 218 barrels gross, including 105 barrels of oil, from the WINN was reported.(31)

In early March, MV WINN was equipped with a side-boom skimmer designed by Union Oil Company. Two self-priming, high capacity centrifugal pumps were employed to transfer the oil through six-inch diameter lines from the skimmer to on-board storage tanks. These pumps were typical of those commonly used for dewatering behind cofferdams and are capable of alternately pumping either air or water containing a considerable amount of

solids. Each pump had a capacity of about 700 gpm and was equipped with a vacuum assist system for self-priming. The oil recovery apparatus consisted of an adjustable trough mounted transversely between two steel floatation cylinders in an open "V" configuration. The oil-water mixture, after entering the trough over the leading edge, was pumped from the bottom of the trough through one of two 6-inch lines. It was estimated that this device, as designed, would recover a 19:1 water to oil mixture. Two 17,500 gallon ship tanks were employed; one for holdup and decanting, and the other for storage of the oil-water emulsion. The mixture was held in the decanting tank approximately 30 minutes before transfer to the storage tank.[23]

This skimming device proved relatively effective while advancing at speeds up to five knots. Initial tests recovered 200 barrels of mixture, including 72 barrels of oil.[32] It was the only skimmer used that was capable of traversing slicks and recovering the "ropes" of oil formed by wind and wave forces and which extended for considerable distances. It was also successfully employed to skim the oil held up by kelp beds near shore. Auxiliary vessels were often employed to locate and windrow the oil ahead of the skimmer. The capacity of the skimmer under ideal conditions and working in a relatively thick slick was about 25 barrels per day. As much as 100 barrels of oil were offloaded every three to four days.[23]

Another skimming device, "Sea Sweep", was constructed for use at sea. This "Sea Sweep" consisted of two 800-foot sections of 20-inch diameter steel pipe joined at one end in the form of a "V" with an opening of between 500-800 feet. Motive power was supplied by tugs. A recovery boat equipped with six pumping stations was to travel at the apex of the "V" and transfer oil to storage barges nearby (capacity, 12,000 barrels). The device encountered severe mechanical problems almost immediately, and the length of the pipe sections was subsequently reduced. Because of its inability to cope with rough seas, operations were terminated in mid-February after one day of operation.[33]

Permanence of the Method - Removal of oil mechanically into tank trucks and barges provided permanent removal.

Additional Damage by the Method - Mechanical removal of oil to tanks and barges produced no additional damage.

Operational Shortcomings and Limitations - Operational problems and limitations encountered during skimming with the side-boom skimmer on the MV WINN were: (1) the piping between the skimming apparatus and pumps contained restrictions subject to clogging when straw or surface debris was encountered; (2) drag forces caused the skimmer to submerge and thus become ineffective when the speed of advance exceeded five knots; (3) the large physical size prohibited lifting the skimmer aboard ship and, therefore, transport to and from the scene was slow; (4) since a vessel tends to turn "on its bow", the side mounting presented a maneuverability problem in following a narrow "rope" of oil; and (5) splashguards were not included on the outriggers or behind the trough and therefore some of the oil was swept over the device in rough seas.

Skimming operations were not practical in winds exceeding 15 knots. Rough seas prevented operation on many occasions. Skimming was limited to daylight operations; therefore, a considerable amount of time was spent skimming oil that had escaped during the night. It is likely that the overall efficiency of this operation could have been improved if the skimming vessel did not have to spend a significant portion of time hunting for oil "ropes", i.e., some improved system of "spotting" would have increased the effectiveness.

The centrifugal pumps tended to emulsify the oil during each transfer operation and severe problems often were encountered offloading the oil to receiving trucks after the oil had been transferred between tanks at sea. A water-in-oil emulsion was formed with the approximate consistency of light grease after two transfer operations with centrifugal pumps. Chemical demulsifiers were occasionally necessary to achieve transfer.(23)

Operational problems of other devices were similar, e.g., straw and debris tended to plug the intakes, too much water recovered (MV WINN with square box and curved boom); worked only on thick oil layers (offshore workboats with suction pumps); inability to cope with rough seas ("Sea Sweep").

Booms

Use of Booms for Harbors - Booms were employed at the Santa Barbara Channel incident primarily as defensive measures for harbors. Prevention of oil in-rush at harbors using commercial booms and log booms was generally successful except at Santa Barbara Harbor where an extremely heavy in-rush of oil presented a severe case. The booms proved effective in relatively calm seas if the oil was continuously removed as it accumulated. An air curtain barrier later installed at Santa Barbara proved effective in sheltered waters, allowing passage of traffic and capable of being turned on and off to take advantage of natural tidal flushing.

Use of Booms on the Sea Surface - Several types of floating booms, including a rigid "corral", were employed to contain the oil on the surface. Most were deployed in the immediate vicinity of the platform to prevent spread of the oil until it could be recovered. Attempts also were made with booms to prevent the slick from moving toward the beaches. In order to contain the oil as it emerged at the surface, very long booms (up to 1,800 feet) were required since the oil spreads rapidly and surface currents caused the boom to take on a catenary shape.(23)

Booms and containment devices employed or tested at sea in the vicinity of the platform to capture or contain the oil slick included:

- Sheets of rubberized asbestos approximately 37 inches high and one inch thick.
- Log booms.
- An inflatable boom 20 inches in diameter with a 30 inch skirt.
- A smaller commercial plastic boom with skirt.
- Rubberized fabric sheet with battens for stiffening.
- A "corral" formed from sheet metal.
- A lattice of steel cables covered with a quilted fabric material.

The log booms were fabricated from telephone poles 30-50 feet long with minimum diameters of 12 inches. Steel cables up to one inch in diameter joined the successive sections and canvas wrapping prevented leakage between sections. The log booms were assembled in lengths up to 1,000 feet or more near shore and towed to the scene. This type of boom generally proved to be ineffective in rough seas because of the inability to conform to the sea surface, thus permitting the oil to be carried over or under. Skirts were not used on the log booms. Several were destroyed by rough seas. Approximately 5,000 feet of log boom was positioned within 1,000 yards of the north side of the platform on February 5.(34)

The commercial booms employed at sea generally range in price from \$8-\$15/foot (without mooring systems). The cost of emplacement, positioning and/or holding is estimated to range between \$20 and \$50/hr, depending on the number of ships required. Makeshift booms, such as those fabricated from telephone poles, are estimated to cost \$4-\$8/foot.[24]

The steel "corral" was an open cylinder approximately 30-35 feet in diameter and 10-12 feet high. The sheet metal outer covering was braced internally with structural members; 55 gallon drums on the inside provided buoyancy. It was to be towed to the scene and moored on the surface over the boil with the intent that the accumulated oil would be pumped out as it collected. However, the "corral" struck a leg of the platform during placement and was damaged beyond repair before it could be tested.[23]

A large boom was formed from a ten inch square lattice of 1/2 inch diameter steel cables covered by a heavy quilted fabric which was claimed to pass water while retaining the oil. The physical dimensions were 10 feet high by 200 feet long; approximately 3-1/2 feet rode out of the water. Buoyancy was provided by plastic foam-filled bags on either side. The 200 foot section was towed to sea for tests in late March and tested for several days. The short length employed did not permit evaluation of the effectiveness to contain oil. However, the boom proved strong enough to survive at least 10 days of relatively calm seas. The cost of this boom was reportedly \$10,000 for 200 feet.[23]

An inflatable boom was also employed in the vicinity of the platform. The configuration of this boom made it difficult to tow at moderate speeds and it failed structurally. A strengthened version was later used across the mouth of the Santa Barbara harbor but was damaged by a ship. A third, further improved, model used plastic foam instead of air for flotation and reportedly worked satisfactorily across the mouth of the Channel Islands Harbor.[23]

Booming was often hampered by heavy seas and a number of severe operational problems such as structural integrity of the boom, mooring, alignment and holding with ships, launching from shore, inability to contain the accumulated oil, and dragging of ground tackle. One of the commercial booms was damaged by a ship's propeller and had to be returned to shore for repairs.[35] The booms were often deployed with one end attached to a buoy while a ship maintained the other end on station. The moorings often parted in heavy seas, thus suspending operations. Positioning posed a problem because lateral forces on the relatively long booms and excessive towing forces caused mechanical failure. Floating debris constituted a navigational hazard and its accumulation against booms also produced severe structural forces. Booms that had a relatively high, narrow rectangular cross section were subject to tipping and thus loss of oil retention capability, particularly if mooring lines slackened. Confinement of oil by an encircling boom placed around the platform, even if it had been possible, might have markedly increased the fire hazard and possibly closed down attempts being made to shut in the well. Complete encirclement would also have restricted ship traffic to and from the platform.[23]

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# APPENDIX C

## PROCUREMENT DATA AND PERFORMANCE NOTES ON EQUIPMENT AND MATERIALS

## APPENDIX C

### I. CONTAINMENT DEVICES

1. "CORK FLOAT" BOOMS - (Commercial)

Cork float booms are constructed from a series of cork discs 6-in. in diameter by 2 in. thick and 3 in. in diameter by 1 in. thick, strung alternately on 3/8 in. diameter polyvinyl coated steel or bronze cable. The cork floats are enclosed in a polyvinyl or canvas cover which may or may not be perforated. These booms are available in 50-ft sections and are normally unskirted. The inherent flexibility of this configuration permits the boom to follow the water profile extremely well. However, without skirts, underslip of accumulated oil can impose a severe problem and, therefore, these booms should not be employed when surface currents or moderate winds are prevalent. Cork float booms cost about $6 per foot. They are durable, easily handled and cleaned, and readily deployed, particularly when stored on reels. The boom is available from a number of vendors. A similar makeshift boom (used at Norfolk) employs granular cork bits surrounded by a 6 in. diameter neoprene fabric covering.

2. "GALVAING" BOOM - Gamlen-Naintre & Cie. (Clichy, France)

This boom consists of rigid floats which are inserted into plastic-coated fabric and attached to PVC-coated flexible asbestos panels. The boom sections (16 to 20 ft) are formed by adding several individual units 3 to 4 ft long providing good flexibility. For extended lengths, connections are provided at the end of each section. Krypton signals are available to provide a warning light up to 75 ft away at night.

The boom is available in three main types: (1) the PB type flexible emergency barrier comes in 20 ft sections with flotation provided by polyurethane-filled floats. Lead ballast of 1.3 lb/ft is fastened to the bottom of the 1/4 in. Navy plywood skirts. Additional ballast is also available for tidal current or towing applications. The maximum dammed height is 8 in. with a working depth of 16 in. (2) A fire control barrier of similar construction employs fireproof floats and a skirt of asbestos cloth with PVC and strengthened with mosquito net mesh cloth. (3) The long-skirted unballasted barrier consists of units identical to the PB barrier with the addition of a neoprene-treated nylon cloth skirt. A galvanized steel chain is threaded through the lower hem of the skirt to maintain vertical stability. The skirt also contains plywood battens with lead ballast attached.

The approximate prices of the three types are as follows:

PB type barrier $13.60/ft ($16/ft with krypton signals)
Fire control barrier $16/ft ($18.50/ft with krypton signals)
Long-skirted barriers $14.80/ft ($17.25/ft with krypton signals)

3. "SEA CURTAIN" BOOM - Kepner Plastic Fabricators, Inc.

This boom consists of a cylindrical floatation section, either foam-filled or air-inflatable with a skirt suspended below. The foam blocks are in short sections for flexibility. Ballast is provided by a chain running through the bottom of the skirt. The fittings at the end of each section are identical to those of the "Slick Bar" and,

therefore these booms may be joined together. The deep skirt permits utilization for dragging or sweeping operations.

The boom is available in four sizes:

a. A heavy duty ocean service foam-filled float 20 in. in diameter with a 30 in. skirt. Approximate price is $10 to $15/ft.*
b. A heavy duty harbor and channel service with foam-filled float. The float is 12 in. in diameter with an 11 in. skirt. The price is $6 to $9/ft.*
c. An emergency containment boom with an inflatable float. The inflated portion is 19 in. in diameter with a 32 in. skirt. The approximate price is $4 to $6/ft.*
d. A light duty emergency containment boom with inflatable float. The inflatable section is 12 in. in diameter with an 11 in. skirt extending below. Approximate price is $2 to $4/ft.*

The length of the extended skirt makes these booms particulary applicable in areas where surface currents are appreciable.

4. "SEA FENCE" BOOM - Ocean Science & Engineering, Inc.

This barrier consists of rigid vertical barriers of aluminum sheets held together by steel cable and provided with foamed plastic material for flotation and neoprene joints to provide a flexible seal between panels. It is fireproof and capable of storage on reels. This boom is produced by the Aluminum Company of America (ALCOA) and will become available in several sizes. A prototype model was tested but not employed at Santa Barbara.

5. "SLICK BAR" MARK IV BOOM - Slickbar, Inc.

This boom consists of a flexible plastic skirt supported by foam plastic floats. The floats are 9 ft long with a 12 in space between each to permit folding and connectors. The boom is lightweight and easily handled. The skirt consists of 0.030-in. thick polyethylene with small lead weights clipped to the bottom. It may be produced in any continuous length up to 10,000 ft.

The boom is accordion-folded for storage in 10 ft folds. Prices range from $3.85/ft for models with a 6 in. skirt and 4 in. float to $12.25/ft for those with a 24 in. skirt and 6 in. float. Additional weights can be added for dragging or skimming operations. The manufacturer claims the boom is effective in surging waves ("green water") to 20 feet in height but not in plunging or spilling breakers. Currents over 1.3 knots (water or wind-driven water) will cause oil to pass under the boom. (See Appendix D, Figure D-1)

6. SOS BOOM - Surface Separator Systems, Inc.

This boom is manufactured in Sweden and distributed in the U.S. by Surface Separator Systems, Inc. It is made in two styles: A permanent boom of

*Based on 5000 ft length FOB Factory

glass-fiber-reinforced polyester and an inflatable emergency boom. The permanent boom is manufactured in 10 ft lengths and consists of 7 in. diameter tubes of fiber glass filled with urethane foam. A nylon reinforced PVC coated skirt provides an 18 in. draft. Chain ballast is fitted into the hem of the skirt. Couplings are provided to fasten sections. The price is approximately $5.50/ft.

The inflatable emergency boom is manufactured in 80 ft sections of PVC air inflated tubing. A 14 in. skirt is provided with chain ballast along the hem. The chain is also used for towing. The 80 ft sections have a unit weight of 0.3 lb/ft and cost $1.40/ft. (See Appendix D, Fig. D-2)

7. "SPILLGUARD" BOOM - Johns-Manville, Inc.

This boom is constructed of asbestos rubber sheet material. Flotation is provided by foam flotation cells attached to both sides of the sheet. Ballast is attached at the bottom of the sheet. The boom is furnished in 100 ft lengths (10 hinged sections 10 ft long) and is accordion-folded for storage.

Two models are available: (1) 4 in. of barrier above the water surface and 11 in. below, costing approximately $7.50/ft, and (2) 12 in. above the water and 24 in. below, costing approximately $20/ft. The larger model is suitable for dragging or sweeping operations. The smaller version weighs approximately 3 lb/ft and the larger approximately 9 lb/ft. The manufacturer recommends the larger size for open water use such as around off-shore drilling rigs. (See Appendix D Figure D-3)

8. "T-T" OIL BOOM - Hurum Shipping and Trading Company Ltd. (Montreal, Canada)

The "T-T" boom is manufactured by the Trygve Thune A/S of Norway and distributed by Hurum Shipping and Trading Company Ltd., Montreal, Canada. The boom is constructed of a nylon skirt with PVC plastic pressed into the cloth on both sides. Foam plastic floats are attached to both sides of the boom and lead weights are attached at the bottom. Aluminum battens sewn into the sheet provide vertical stability. The boom is stored by folding accordion-wise; the same folding can be used to reduce the boom enclosure area.

The boom is fabricated in sections 164 ft long by 3 ft high (1 foot of free board) and has a unit weight of 1.5 lb/ft.

9. "WARNE" BOOM - William Warne and Company, Lt.. (Barking, Essex, England)

Warne boom is constructed of thin fabric-reinforced synthetic rubber. It consists of an air inflatable flotation tube and skirt with a chain pocket at the bottom. The flotation tube can also be filled with short sections of synthetic foam or polyethylene tubing sealed at 2-foot intervals and is available in either 8 or 16 in. diameters with a 22 in. skirt. Foam or tube filled booms are recommended for permanent installations.

The inflatable version can be used as a rising and sinking boom to permit crossing by ships. This is accomplished by inflating or deflating the middle sections. The inflatable boom is pressurized to 40 psi. The price of the inflatable boom varies from $17.60 to $23.40/ft, depending on size and capability. The tube filled models cost from $23.80 to $30.50/ft. The boom can be assembled from individual 25 or 50 ft sections. The heavy weight of this boom makes it hard to tow or deploy rapidly. The boom is manufactured by William Warne and Company, Ltd. of England and distributed by Surface Separator Systems, Inc. (See Appendix D, Figures D-4, D-5 and D-6)

10. WOODEN TIMBER BOOMS

Make-shift booms can be fabricated by joining short sections of wooden timbers together and wrapping the joints with canvas to prevent the oil leakage. This type of boom can be fabricated from any available wooden sections and in some cases satisfactory booms have been constructed from used telephone poles joined by steel cable. The one disadvantage is a lack of sufficient flexibility unless very short sections are employed. An obvious advantage is low cost. This type of boom could not be expected to contain oil on open seas with waves of up to 5 feet because of inadequate freeboard and depth.

11. "RODE ORM" (RED EEL BOOM) - Trelleborg Rubber Co., Inc.

The "Rode Orm" boom was developed by Erling Blomberg of Gothenburg, Sweden and is being used in Sweden to control oil spillage. The device consists of a 23-1/2 in. high boom floating on the water, two-thirds submerged. A separate load relieving line on either or both sides of the boom is employed to reduce tensile forces on the boom. It is made of 2-ply polyvinylchloride foil with pockets containing sand ballast and cellular plastic flotation material and comes in 164 foot lengths that can be combined to any desired length. The boom is claimed by the manufacturer to be inexpensive enough to be disposable or can be used several times. Cost of the boom is \$2.60/ft. The manufacturer states that 1000 ft can be layed in 7 minutes using an anchor system and untrained people. A high sea wreck boom called the "Troll", currently under development, will be of similar construction, four ft high and will cost about \$14/ft. (See Appendix D, Figure D-7)

12. "KAIN OFFSHORE FILTRATION BOOM" - Starcross Oklahoma, Inc. (Bennett International Services, Inc.)

Constructed in 100 and 150 ft inter-locking sections, 8 ft in depth, the Kain boom is supported by 10 foam filled cylinders, 14 in. in diameter evenly distributed on each side of the boom. A 1/2 in. steel cable net incased in 8 foot squares of a specially processed fibrous polypropylene filtering material, forms the deep skirt. The freeboard is 2' -6" while the skirt is submerged 5' -6". In tests conducted at Santa Barbara, it withstood heavy rolling seas (in excess of 14 ft) and gale force wind, according to the manufacturer. There are two 40 foot cables attached for towing or anchoring purposes. Oil collection and retention occurs by selective movement of water but not oil through the porous skirt. After use the boom must be cleaned, which can be accomplished with hydraulic jets. (See Appendix D, Figure D-8)

13. "OSCARSEAL" SYSTEM - The Rath Co. and Morrison-Knudsen Co.

The "Oscarseal" system is a series of interconnected "captured air" floats designed for containment of oil slicks on open seas such as around a distressed tanker or off-shore platform. Standard floats are fabricated from steel plate in 40 foot lengths. Air is expelled from one side of the float by means of a textile "air skirt" on the inner circle side to push the oil away from the boom. Each float has its own air supply system which can have a self-contained power supply or remote power from a ship or a floating plant forming part of the system. A hinged plate is attached to act as a depth shield and keel, and extension curtains may be attached for high sea state conditions.

Adjacent floats are connected by two clip links and a steel cable is provided for the top side as a safety device, for service of the embedment anchors and for towing purposes. Foam flotation is provided to keep the system afloat without air. (See Appendix D, Figure D-9)

14. CONWAY RETAINER WALL - Offshore Safety Systems, Inc.

The Conway Retainer Wall is a system of multiple bag units which are joined to form a boom and is recommended by the manufacturer for retarding spillage from ship accidents, drilling platforms, coastal area protection and sweeping up slicks.

Each individual unit consists of six cells. Each cell contains approximately 200 individual bags, filled with either rubber or styrofoam. The units are designed for anchoring with either a single (one side) or double (both sides) cable system using 7/8" cable. The bottom of the boom normally rests about 18 inches below the surface. It is claimed that it can be assembled quickly, and in an emergency, in situ chemical foaming may be used to produce the boom. Each unit is 7 ft x 5 ft x 30 inches high. The system is equipped with oil retainer fins between units, and a rough seas underwater skirt is available.

The manufacturer claims the boom will withstand 10 foot swells and 30 mph winds. Cost of each six-unit cell is about \$400 (about \$57/ft). (See Appendix D, Figure D-10)

15. "MP BOOM" - Metropolitan Petroleum Petrochemicals Co., Inc.

The "MP Boom" is made of flexible low density flotation material and is designed for easy handling and storage. It is supplied in 100 foot lengths. The buoyant section is 6 inches in diameter and has a 12 inch skirt. A six-foot keelson is used in each section to keep the boom skirt down. A 100 foot length can be stored in a space 7 ft x 3 ft x 3 ft. A stress cable, rated at 2000 lbs., is located at the base of the skirt to enable towing and corralling operations. The price is \$7.85 per lineal foot with discounts available up to 60¢/ft for large orders. (See Appendix D, Figure D-11)

16. NAVY HEAVY DUTY OIL POLLUTION CONTAINMENT BOOM - Long Beach Naval Shipyard (Murphy Pacific Marine Salvage Co.)

This boom consists essentially of 4 x 8 foot sheets of exterior grade plywood with empty 55 gallon drums attached to each side for flotation. Plasticized canvas is used at the attachment between sections with towing loads being taken by 1/2" wire rope stress wires attached at the outside edge of the 55 gallon drums. The boom system consists of dead weights and buoys for placement at approximately 50 foot centers when used as a harbor protection boom between breakwaters. (See Appendix D, Figure D-12)

17. "JATON" FLOATING OIL RETAINERS - Centri Spray Corp.

The "Jaton" boom is available with a float size range of from 3 to 6 inch diameter by nine feet long sealed in vinyl-coated nylon skirts of up to 24 inches. The ten foot sections of the boom are joined by a 6 inch thermal seam. Longer lengths are joined at 6 inch overlapping connections using brass grommets and rope to maintain the connection. Keel weights are 4 inch by 3/8 inch diameter galvanized steel bars sewn into the skirt material. Unicellular plastic foam ("Ethafoam") is used as the flotation member. (See Appendix D, Figure D-13)

18. "MULLFLEX" HIGH SEAS OIL SPILL CONTAINMENT BOOM - Muehleison Manufacturing Company

A five foot by 100 foot length boom is produced using "Ethafoam" floats and a vinyl-nylon material skirt with two feet above and three feet below the surface. It is claimed to be designed and adequately ballasted to provide an effective barrier and skirt shield for the containment of oil spills on high seas. The top edge is reinforced with PVC pipe and rope hem with rope insert and the bottom skirt leading edge is weighed to maintain the boom upright. Each 100 foot section folds on 3'-4" centers for storage and weighs 500 lbs. The bottom leading edge has a rope hem and rope insert with grommets for fastening a continuous chain. The function of the chain is to relieve stress on the boom during pulling and installation. Price - $15.00 per lineal foot, FOB San Diego, Calif. (See Appendix D, Figure D-14)

19. "BRISTOL FLOATING BOOM" - Rolls Royce (Composite Materials) Limited (Bristol, England)

Designed for protection of harbors and coastal waters, the "Bristol" boom is made in 20 foot lengths with quick assembly by means of mechanical couplings. Lengths of 10 inch diameter glass reinforced plastic pipe, sealed at each end provide buoyance. A 9 inch ribbed fin and a 12 inch deep hooded skirt are made of laminated plywood. Balance weights, attached by means of steel angle iron, provide the counter movement to tide and current loads on the boom. These also stabilize the boom for towing. A 20 foot section weighs 170 lbs. without balance weights. The boom floats such that there is approximately 16 inches above and below the still water line. (See Appendix D, Figure D-15)

20. THE "OIL BARRIER" (CONCEPT) - Eugene C. Greenwood, Sr.

Hinged steel plates with attached float sections form the boom contour. The boom cross-section is such that the 4-6 foot depth is angled toward the oiled area. The upper 2-4 foot section is then curved to form a splash plate effect. The boom is attached through a buoy to a bottom dead weight for placement. Arranged circularly about a drilling platform, it is claimed to be able to contain a release of 500 bbl./day for a five day period (should storms prevent pumping the oil from the barrier).

21. FLOATING BREAKWATER BOOM (CONCEPT) - Peter Bruce (Edinburgh, England)

The breakwater consists of a flexible cylindrical shell moored horizontally, so that its upper surface is approximately at the still water level, and contained in a netting envelope to distribute mooring forces evenly. It is filled on location with sea water and a small volume of pressurized air sufficient to provide buoyance and maintain the shape of the cylinder. Such an arrangement gives the cylinder an infinite natural period of oscillation in roll and long periods in pitch and heave. Its large diameter, chosen to exceed the peak-to-trough amplitude of the largest waves expected, gives it additional stability so that it remains substantially stationary even in the heaviest seas.

For protecting drilling platforms, the ring of cylinders has a much longer natural period than the individual sections so it is more effective at longer wavelengths. Additional protection can be provided by mooring extra cylinders inside the windward part of the lagoon.

The cost of the lagoon depends on the degree of calm desired, the amplitude of the largest waves and the area of the lagoon. For example, waves 10 metres high and 100 metres long can be reduced to little more than one metre high in the center of a

lagoon 120 metres in diameter at an estimated half to one third of the cost of a semi-submersible drilling platform.

22. ROUGH WATER OIL CONTAINMENT SYSTEM (CONCEPT UNDER DEVELOPMENT) - Deepsea Ventures, Inc.

This boom system features a tension member separate from the containment boom to take the structural loads and enable the boom to contour the ocean surface. (See Appendix D, Figure D-16). Floats may be spaced along the tension line if required, or if used in connection with oil removal services, the tension line may have negative buoyance to ride below the surface. The skirt of the boom may have two point support to assist in holding the skirt in a vertical plane. For rough water service, a horizontal member may be attached on the oil retaining side to assist in preventing oil carryunder from vertical heaving and turbulence. The boom is intended to be used in connection with an oil recovery system using a device such as an oil suction hose connected to the boom skirt (See Appendix D, Figure D-17). The construction of the oil removal device would be designed to enable a stationary vessel to contain the equipment for pumping the air and oil film. Patents have been applied for on the separate tension member and oil collector system. The system is said to be designed for use in seas up to 20 to 40 feet with winds of 40 knots.

## II CHEMICAL AGENTS

| Product and Source | Manufacturer's Recommended Application Ratio (a) | Approximate Cost (b) | Remarks |
|---|---|---|---|
| **Dispersants** | | | |
| Alken O.S.D.<br>Alken-Murray Corp. | 1:10 to 1:15 | $2.99/gal. | Aromatic solvent diluent - 50%. Not for use below -5° F. Flash point 180° F; Sp.gr. 0.904. |
| Ameroid Oil Spill<br>Emulsifier No. 1<br>Drew Chemical Corp. | 1:20 to 1:33 | $3.25/gal. | Contains solvent and ethylene dioxide condensate. Flash point 168° F; Sp.gr. 0.96. |
| Aquanex MC<br>Montgomery Chemical Co. | 1:10 | $1.40/gal. | Polyglycols with petroleum naphtha diluent. Flash point 180° F; Sp.gr. 0.83. |
| B & B 2021-S<br>B & B Chemical Co., Inc. | 1 gal/50–100 sq. ft. of thin slick. | $2.20/gal. | Soaps 30–50%; aromatic solvents 48–65%; inhibitors 2–5%. Flash point >150° F; Sp.gr. 0.91. |
| B & B 2023<br>B & B Chemical Co., Inc. | 1 gal/50-100 sq. ft. of thin slick. | $2.85/gal. | Non-ionic detergents 70%; water 30%. Sp.gr. 1.01. |
| Bacto-Zyme<br>Nevada Enzymes, Inc. | 1:5000 | $3.95/gal. | Ferment of organic materials 92%; polyglycols 2%; amines 4%; esters 2%. Dosage rate estimated by Mfr.; no data to substantiate. Also functions as a biological degrading agent. Use above 50° F. Not effective on Bunker C. |

(a) Parts agent per part of oil by volume unless noted otherwise.
(b) Based on one-drum quantities (52–55 gal. drum).

| Product and Source | Manufacturer's Recommended Application Ratio | Approximate Cost | Remarks |
|---|---|---|---|
| Besco B-51-DT<br>The Besco Corporation | 1:2 to 1:4 | $1.80/gal.<br>FOB New Orleans | Detergent type with surfactants. Non-flammable. |
| Besco D-Emulsion<br>The Besco Corporation | 1:2 to 1:4 | $1.60/gal.<br>FOB New Orleans | Aliphatic hydrocarbons, non-ionic surfactants. Flash point 120 to 140°F. |
| Besco Slick 440<br>The Besco Corporation | 1:2 to 1:4 | $1.90/gal.<br>FOB New Orleans | Proprietary product. Flash point 100 to 120°F. |
| Blitz<br>The Clarkson Laboratories, Inc. | 1:15 | $1.95/gal. | Proprietary product. Control of oil, gasoline and jet fuel spills. Not for Bunker C. Non-flammable. |
| BP-1002<br>BP North American Ltd. | 1:10 to 1:5 | $1.08/gal.<br>FOB England | Non-ionic emulsifiers in an aromatic petroleum solvent (60-70% aromatics). Used extensively in TORREY CANYON. Relatively toxic to marine life. |
| BP-1100<br>BP North American Ltd. | 1:10 | $1.10/gal.<br>FOB England | Oil soluble non-ionic emulsifier in petroleum solvent. Relatively non-toxic to marine life. $LD_{50}$ 3300 ppm. Highly flammable. Flash point 80°F. |
| Casol<br>Wyandotte Chemical Corp. | 1:5 | $2.00/gal. | Solvent base emulsifier. Works best in fresh waters; but has been successful in sea water. Flash point 200°F. |

| Product and Source | Manufacturer's Recommended Application Ratio | Approximate Cost | Remarks |
| --- | --- | --- | --- |
| Corexit 7664<br>Enjay Chemical Co. | 1:10 to 1:50 | $3.90/gal. | Proprietary product – water and alcohol diluent. Relatively non-toxic: $TL_m$ (96 hr) = 1800 to 3200 ppm on fathead minnows. Flash point 175° F. |
| Corexit 8666<br>Enjay Chemical Co. | 1:10 to 1:100 | $3.90/gal. | Proprietary product – aliphatic hydrocarbon diluent. Particularly effective on heavy-viscous fuels. Relatively non-toxic: 24 hr. acute toxicity test on tropical fish showed non-toxic at 10,000 ppm. |
| Dart<br>Sea-Air Chemical Corp. | 1 gal. to 5 gal. of water using hoses. | $1.45/gal. | Recommended for tank degreasing. Flash point 170° F. |
| DI–CHEM 320<br>Diversified Chemical Corp. | 5:1 to 1:50 | $2.15/gal. | Water diluted proprietary product. High pressure sprayer agitation (500–2000 psi) is recommended. Non-flammable. |
| Disperse–Oil<br>Pepper Tank Cleaning Co. | 1:1 to 1:10 | $1.25/gal. | Water diluted proprietary product. High pressure sprayer agitation (300 psi) is recommended. Not effective on heavy asphaltic residuals. Non-flammable. |
| Dispersol OS<br>Imperial Chemical Industries, Inc. | 1 to 5 tons per acre of slick. | $2.76/gal. | Polyethanoxy compound and isopropanol. Recommended for fresh and weathered crude oils and distillate fuels. Highly inflammable, flash point 53° F. (Abel closed cup). Relatively non-toxic. $LD_{50}$ (brown shrimp) 3300 to 10,000 ppm. |

| Product and Source | Manufacturer's Recommended Application Ratio | Approximate Cost | Remarks |
|---|---|---|---|
| F.O. -300-B<br>F.O. -300-H<br>Fine Organics, Inc. | 1:2<br>1:2 | \$1.80/gal.<br>\$1.80/gal. | Non-ionic, aromatic hydrocarbon and adiphatic hydrocarbon. Flash point 180°F for 300-B and higher for 300-H. |
| Foilzoil<br>Sea-Air Chemical Corp. | 1 gal/100 sq.ft. | \$2.05/gal. | Proprietary product containing polyglycols, not combustible. Harmless to fish and plant life (Manufacturer). |
| GAMOSOL Oil Spill Remover<br>Gamlen Chemical Co. | 1:6 to 1:10 | \$3.25/gal. | Polyglycols, polyethanol and aromatic hydrocarbons. Claimed to be 95+% effective. Meets Mil. Spec. 22864A (ships). Flash point >150°F. |
| Gold Crew Dispersant<br>Ara Chem. Inc. | 1:5 to 1:15 | \$2.75/gal. | Water based concentrate, largely non-ionic with lesser amounts of Alkyl-aryl sulphonates. No flash point. |
| Hemco No. 2<br>Hemisphere Marine Chemicals Co., Inc. | Not reported | \$2.75/gal. | Solvent type emulsifier. Recommended for treatment of polluted beaches and harbor waters. |
| Holl-Chem No. 622 Oil Spill Dispersant<br>Holl-Chem. Inc. | 1:10 | \$3.30/gal. | Polyglycols, alkyl-aryl sulphonates and aromatic petroleum diluent. Agitation is required for flat calm conditions, not effective on weathered crudes. Flash point 205°F. |
| Igepal CO-430<br>CAF Corporation | 1:33 to 1:100 | \$0.21/lb. | Ethoxylated nonylphenol and ethylene oxide. Flash point 500-600°F. (Mfr.). |
| Igepal CO-530<br>CAF Corporation | 1:33 to 1:100 | \$0.21/lb. | Ethoxylated nonylphenol and ethylene oxide. Flash point 480-510°F. (Mfr.). |
| Isomal 265<br>Johnson-March Corp. | 1:1000 to 1:5000 (Manufacturer) | \$2.44/gal. | Active sulphonated ester with water diluent. Flash point 400°F. |

| Product and Source | Manufacturer's Recommended Application Ratio | Approximate Cost | Remarks |
|---|---|---|---|
| Jansolv-60<br>Jansolv-60W<br>Sunshine Chemical Corp. | 1:91 to 1:191 (Mfr.)<br>1:2 to 1:10 (others) | $2.00/gal. | Proprietary product, water base with a small amount of petroleum hydro-carbons and surface-active agents. Flash point 154°F. Jansolv-60W is used for low temperature application and storage, to 15°F. |
| LCP-12<br>Crain Industrial Products Corp. | Not reported. | $2.30/gal. | Proprietary product, not flammable. |
| LIX 336<br>The Lix Corporation | Not known by Mfr. | $0.80/gal. | Tetra potassium pyro-phosphate water, solvents, couplers and wetting agents. Recommended for cleaning surfaces coated with Bunker C or distillate fuels. Does not burn. |
| Magic Power Oil Dispersant OD No. 1<br>Lawton Specialty Co., Inc. | 1:50 | $3.35/gal. | Wetting agents, emulsifiers and naphtha diluent. Flammable in un-diluted form. Flash point 176°F. |
| Magnus Oil Spill Disperser<br>Magnus Chemical | 1:3 to 1:20 | $2.58/gal. | Alkyl-aryl benzene, non-ionic wet-ting agent and petroleum solvent. Best results at 50°F and above. Heavy asphalt residuals not well treated. Flash point 170°F. |
| Met Aquaclene 100<br>Metropolitan Petroleum | 1:3 to 1:12 | $3.75/gal. | 100% alkanolamides. Flash point 350°F. |
| OD-2<br>Crain Industrial Products Corp. | 1:6 | $2.45/gal. | Proprietary product. Non-flammable. |

| Product and Source | Manufacturer's Recommended Application Ratio | Approximate Cost | Remarks |
|---|---|---|---|
| 88 Oil Slick Dispersant<br>Colloid Chemical Co. | 1:2 to 1:50 | \$3.95/gal. | Proprietary product. Non-flammable. |
| Oil Spill Eradicator X-1-11<br>Xzit Chemical Co. | 1:10 to 1:50 | \$3.30/gal. | Polyglycols, amines and esters. Recommended for temperatures of 50°F and greater. Flash point-none. |
| Polyclens<br>Polycell Products Ltd. | 1:2 to 1:4 | \$1.09/gal.<br>FOB England | Polyglycols and petroleum naphthas. Flash point 116 to 120°F. |
| Polycomplex A-11<br>Guardian Chemical Co. | 1:7 to 1:12 | \$3.75/gal. | Amine-amido complex with water diluent. Rated 1 (best) on a scale of 1 to 4 for effectiveness (State of Washington Pollution Control Commission tests). Flash point 370°F. |
| Ridzlik<br>Ashland Chemical Co. | Not specified. | \$1.50/gal. | Proprietary product - bio-degradable surfactant and water diluent. Not specifically recommended for Bunker C. Possibly flammable. Flash point 95°F. |
| Seamulso E<br>Turco Chemische Production. N. V. | 1-5 liters/$m^3$ of surface | \$2.17/gal.<br>FOB Holland | Proprietary product, aromatic diluent. Flash point 151°F. |
| Skanex S 102<br>Scandinavian Oil Service | 1:2 to 1:10 | \$3.65/gal.<br>FOB Sweden | Polyglycolethers and naphtha diluent. Recommended on sea water spills (not fresh). Not recommended on "Chocolate Mousse". Recommended for temperatures greater than 38°F. Flash point 153°F. |
| Slix<br>Amerace-ESNA | 1:8 to 1:20 | \$3.07/gal. | Non-ionic alkyl-phenoxy ethoxyethanol with water diluent. Recommended for use between 50 to 80°F. Does not burn. |

| Product and Source | Manufacturer's Recommended Application Ratio | Approximate Cost | Remarks |
|---|---|---|---|
| Spill Remover<br>Syandotte Chemical Corp. | 1:3 to 1:5 | \$2.55/gal. | Polyglycols and aromatic solvents. Passes Mil. Spec. MIL-S-22864A (ships). Flash point 160°F. |
| Spill-X<br>Pacific Chemical | Data not reported. | \$3.45/gal. | Proprietary product. Rated 1.5 on a scale of 1 to 4 (State of Washington Pollution Control Commission tests). Flash point 220°F. |
| Surflo RD282<br>National Lead Co. | 1:10 to 1:100 | \$3.25/gal. | Oxyalkyated ester, oxyalkyated alcohol. esters, water diluent and alcohol diluent. Works best when wave action is high. Not recommended for potable water (affects taste). Toxicity test showed 100% survival of tropical fish (black mollies) at 1000 ppm. Flash point 168°F. |
| Talent<br>Wyandotte Chemical Corp. | 1:1 to 1:40 | \$3.15/gal. | Non-ionic detergent and water diluent. Recommended for distillate fuels or light oils. It may produce a foam. Flash point 200°F. |
| TEOC 444<br>TEOC, Inc. | 1:10 | \$3.30/gal. | Proprietary product. Non-ionic surfactants, aliphatic solvent diluent. The heavier the crude, the poorer the performance. Flash point 104°F. |
| TEOC 777<br>TEOC, Inc. | 1:20 | \$3.30/gal. | Non-ionics with aliphatic diluent. The heavier the crude the poorer the performance. Flash point 104°F. |
| Tyfosol 80<br>National Research and Chemical Company | 1:33 to 1:50 | \$5.00/gal. | Polyglycols, amines and non-ionics. Passes MIL-C-22230 tests. Flash point 150°F. |

| Product and Source | Manufacturer's Recommended Application Ratio | Approximate Cost | Remarks |
|---|---|---|---|
| W-1439<br>Petrolite Corporation | 1:5 to 1:10 | $2.90/gal. | Acyl amide, dipropylene alcohol, iso-propanol and water diluent. Works well in both fresh and sea water. It is bio-degradable. Flash point 94°F. |
| WF-36<br>Petrolite Corporation | 1:5 to 1:20 | $2.00/Gal. | Alkyl-aryl sulphonate and aromatic solvent. Not recommended for use in confined bays or sloughs. Flash point 136°F. |
| **Burning Agents** | | | |
| Cab-O-Sil ST-2-0<br>Cabot Corporation | 1:10% w/w | $1.95/lb. | Produces a wicking effect. Requires 0.06 to 0.08 inch thick oil film. Works best on heavier oils. Burns up to 98% of a thick layer |
| Pyraxon<br>Guardian Chemical Corp. | 2 to 4 lb. per 100 gal. oil. | $2.90/lb. | Contains oxidizing agent and oil cracking catalyst. Requires 1/8" thick oil film. Works best on heavy oils. Not effective in heavy wave action. |
| SeaBeads<br>Pittsburgh-Corning Corp. | 0.10 lb sq. ft. | $0.90/lb.<br>FOB Missouri | Cellated glass beads. Requires 0.03 inch thick oil film. Reported to be effective on all oils to 21°F. Burns close to 100% in laboratory tests. |

| Product and Source | Manufacturer's Recommended Application Rate | Approximate Cost | Remarks |
|---|---|---|---|
| **Biological Degrading Agents** | | | |
| Bacto-Zyme<br>Nevada Enzymes, Inc. | 1:1000 | $3.95 gal. | Dosage rates estimated by Mfr.; no data to substantiate. Use above 50°F. Not effective on Bunker C. |
| DOC Plus<br>Gerald C. Bowers, Inc. | 1:400 | $5.95 lb. | Bacteria in wheat bran. Only effective on thin slicks. Requires addition of floating material to maintain contact with oil. Dilute 1 lb. to 250,000 gallons of water for use; not for open sea. |

## III CHEMOMECHANICAL AGENTS

| Product and Source | Manufacturer's Recommended Application Ratio | Approximate Cost | Remarks |
|---|---|---|---|
| **Sinking Agents** | | | |
| AP-10<br>Aqua-Pura, Inc. | 2-1 2:1 w/w | $58/ton | Kaolinite and amorphous silica (beta-crystobalite). Non-toxic. |
| Calidria Asbestos-Grade R-G444<br>Union Carbide Corporation | 6-15% w/w | $65/ton* | Chrysotile asbestos-surface treated. Specific gravity 2.4. Not effective on emulsified oils. Flash point-none. |
| Megsite<br>Waverly Mineral Products Co | 1:1 to 1:3 w/w | $50 ton*<br>$35 ton** | Hydrated magnesium aluminum silicate. Bulk density-27 to 33 lb/ft$^3$. Flash point-none. Non-toxic. Also used as a sorbent. |
| Mistron Vapor<br>Cyprus Mines Corporation | 2:1 to 3:1 w/w | 4-6c/lb.** | Not effective on Bunker C or heavy fractions. Specific gravity 2.75. Does not burn. |
| Omya Hartex H<br>Pleuss-Staufer (North American), Inc. | 1:1-1:2 w/w | $80/ton | Hydrophobic calcium carbonate treated with stearic acid. Specific gravity 2.7. 90% effective, non-toxic material. |
| Sol Speedi-Dri<br>Engelhard Minerals and Chemicals Corp. | As required (Mfr.). | $41 ton** | Fuller's Earth (Attapulgite). No toxic limit to marine life. |

*Price for 1 ton lots.
**Price for car load lots.

| Product and Source | Manufacturer's Recommended Application Ratio | Approximate Cost | Remarks |
|---|---|---|---|
| Zorb–All<br>Wyandotte Chemical Corp | Apply to oil surface as necessary. | $60/ton | 100% calcinated clay. Density 35 lb/cu. ft. Used primarily for on deck or loading spills where either a quick pickup is required or sinking is desired. Inert and non-toxic. |
| **Sorbents** | | | |
| Airsorbent 1012<br>Cabot Chemical Co | 2:1 | $6.00/4 cu.ft. bag (18 lb.) FOB Mass. | Silicone treated, expanded pumice of volcanic rock origin. Density 6 to 7 lb/cu.ft. Non-flammable. Agitation by high pressure hoses or mechanical means is helpful. Repels water. |
| Bibbysorb<br>Bibby Chemicals Ltd | 1:40 to 1:50 w/w | $0.51 lb.* | Polyurethane foam. Density of foam 1/2 lb/cu.ft. Flash point not reported. Recommended for bay or harbor use on fresh crudes and distillate fuels in calm sea conditions. Disposal recommended is to squeeze out oil and burn the used foam. Effectiveness is reduced for thicker oils. Foam is non-toxic. |
| Calidria Asbestos-Grade RG-144<br>Union Carbide Corporation | Data included in section on sinking agents | | Removal by strainers, sieves, or skimmers. At 10% agent, agglomerated mass floats. |

*Price for 1–5 ton lots.

| Product and Source | Manufacturer's Recommended Application Ratio | Approximate Cost | Remarks |
|---|---|---|---|
| Capillanfoam<br>U F Chemical Corp | 1 cu.ft./50 lb. of oil | 25–75¢ per cu.ft. | Urea formaldehyde foam. Density 0.6 lb/cu.ft. Non-burning material. Removal by screens or other mechanical devices, or burned in situ. Less effective on high viscosity oil. Inert and non-toxic foam. |
| Conwed Petro-sorb<br>Conwed Corporation | 1:15 w/w | Not reported. | Cellulose (wood fiber) with proprietary surface treatment. Density 1.5 lb/cu.ft. For pickup of weathered crudes, additional treatment is necessary. Non-toxic to marine life. |
| Ekoperl<br>Grefco, Inc. | Not reported. Up to 1:5 w/w. | $0.13/lb in bag lots (4 cu.ft.–24 lbs.) | Aluminum silicate (perlite) with surface treatment. Harvested by use of screens, shovels or vacuum hoses. Burning may be possible. Non-toxic to marine life. Respirators should be used (dusty). |
| Emtal XT-1<br>Engelhard Minerals and Chemicals Corporation | 2 lb/gal of oil sorbed. | $60/ton*<br>FOB Johnson, Vt. | Talc (magnesium silicate) stearate modified. Fifteen minutes of sea water agitation is recommended. Removal by shovel or other conventional means. Non-toxic. |
| [illegible]<br>[illegible] Mineral Products Co | Data included in section on Sinking Agents. | | |

*Price for carload lots.

| Product and Source | Manufacturer's Recommended Application Ratio | Approximate Cost | Remarks |
|---|---|---|---|
| Microtale ZSC<br>Cyprus Mines Corporation | 2:1 to 3:1 | 6¢ to 10¢/lb.* | Talc, 10 micron (100% organophilic: 100% hydrophilic). Manual harvesting is the only mechanism used to date. Not effective on Bunker C or heavy fractions. Non-toxic. |
| 3M Brand Oil Absorbing Microfibers<br>3M Company | Up to 1:20 w/w | Price not established as of Nov. 1, 1969 | Polymeric fiber, treated. Disperse with commercial blower for leaves or straw. A moving belt screen on the front of a barge is used to recover. Using a squeezing method, the oil and the agent may be reclaimed for further use. Absorption speed slows for Bunker C in cold weather. Not effective on tar or asphalt-like products. |
| Oil Blotter<br>Ramer Equipment Co. | 1-1/4 cu.ft. bag will absorb 35 to 48 lb. of crude oil. | $2.50-3.50/bag depending on quantity. | Carbamide urea foam in porous polypropylene bags. Density 0.5 to 0.7 lb/cu.ft. One to 8 hours required for absorbing (proportional to viscosity). Water must be free of wetting agents. Oil is removed by pressing the recovered bags. Non-toxic. |
| Oil Gobbler<br>Polymer Research Corp. | 1:50 to 1:100 w/w | 50¢/lb. | Proprietary product. Density 2 lb/cu.ft. Apply by blowers with agitation required. Recovery of treated agent is feasible, oil being extracted by heat or pressure. Non-flammable, non-toxic. |

*Price for truck load lots.

| Product and Source | Manufacturer's Recommended Application Ratio | Approximate Cost | Remarks |
| --- | --- | --- | --- |
| Osmun No. 3 Oil Absorbent<br>Casmain, Inc. (Tokyo) | 85 to 136 cc. oil absorbed per 100 gm. agent. | Not reported. | Proprietary product, treated with surfactants. Specific gravity 2.2. |
| Perlite King SRD-32<br>Filter Media Co. | Unknown (Mfr.) | \$2.50/4 cu.ft. bag. | Silicone treated perlite. Density 7.0 lb/cu.ft. A broadcast spreader is used for application with harvesting accomplished by the use of booms and scoops. The mass is burned or dumped. Protected waters are recommended. Used on light oils as well as crudes. Non-toxic. |
| Sorbent Type C<br>Clear Water, Inc. | 1 cu.ft. (agent) to 2.25-3.85 gallons of oil. | \$4.25/bag (4 cu.ft.-18 lb.). | A fiberous material of density 4.5 lb/cu.ft. Use a mechanical broadcaster and harvest with nets. Absorbs only oil. Non-flammable. Chemically inert (non-toxic). |
| SOSOL<br>Scandinavian Oil Service (Sweden) | 2:1 | \$20/10 cu.ft. bag. | Shredded polyurethane foam. Density 10 kg/cu.m. (0.62 lb/cu.ft.). The agent may be reused or the agent/oil mass may be burned. |
| Stepanpol RM 15<br>Stepan Chemical Co. | 1 lb/10 gal. of oil. | \$0.52/lb. for solutions. \$0.375/ 1-1/3 cu.ft. of foamed material (approx.) | Polyurethane foam. Density 0.5 lb/cu.ft. Foam can be made in situ (5 min. curing time and then shredded). Remove by confining with a boom and physically retrieving. Recovery of oil and agent is possible by squeezing. Non-toxic. |

| Product and Source | Manufacturer's Recommended Application Ratio | Approximate Cost | Remarks |
|---|---|---|---|
| Straw | 1:5 w/w | \$24-35 ton | Wheat straw (not hay) absorbs about five times its weight of oil. Used primarily in beach cleaning but has been applied at sea and in harbors. Retrieval is laborious. Used extensively at Santa Barbara (1969). |
| [illegible]<br>[illegible] Industries, Inc. | Data included in section on gelling agents. | | |
| Typar<br>E. I. duPont de Nemours, Inc. | 1:10 w/w | \$1.00/lb. delivered (approx.) | Porous fabric of linear polypropylene, spun bonded, continuous filament. Density 2-1/2 to 4 oz./1 sq.yd. (sheet form). Use on belt type recovery system or tow behind vessel or between two lines. Separation by squeezing or vacuum extraction. Agent is reusable. Non-toxic. |
| Tyvek<br>E. I. duPont de Nemours, Inc. | 1:10 to 1:30 w/w<br>1:200 to 1:500 w/w in loose form. | \$1.00-1.10/lb. | Linear polyethylene porous fiber continuous filament. Essentially non-reusable, non-toxic. |
| Wonderperl 1640<br>Perlite Popped Products | 1-1.2:1 | \$0.33/cu.ft. (4 cu.ft. bags) | Silicon and alumina expanded, applied using underwater blowers. Harvesting as with kelp. Best results are expected with lower viscosity oils. Non-toxic. |
| Zorb-A3<br>Wyandotte Chemical Corp. | Data included in section on sinking agents. | | |

| Product and Source | Manufacturer's Recommended Application Ratio | Approximate Cost | Remarks |
|---|---|---|---|
| **Gelling Agents** | | | |
| Spill-Away<br>American-ESNA Corp. | 1:2 to 1:3 | $3.00/gal.*<br>FOB California | Gels oils and gasoline when agitated in presence of water. Limited to sea states where booming and harvesting practicable. Oil could be recovered. Flash point 155° F: Sp.gr. 0.84. |
| [illegible]<br>[illegible] Industries, Inc. | 1:10 to 1:30 W/W | $0.45/lb. | White granular solid. Also functions as sorbent. Oil can be recovered by pressure or naphtha extraction. Material is re-usable. |

*[illegible]

## IV. MECHANICAL TREATING EQUIPMENT

### SKIMMING WITH SUCTION DEVICES

1. RHEINWERFT OIL - REMOVAL UNITS - C. A. Bekhor, Ltd. (London)

   Basically the device comprises three circular pontoons triangularly strutted together. Inside, a floating basin is located, where the water level is lowered by means of a pump. Floating oil flows into this artificial well where a second pump provides a means to draw off the surface oil from the well. It is claimed that 100 percent oil is recovered. The device is operable on thick or thin slicks, provided they are "pumpable". Units are manufactured in a number of sizes ranging from 500 to 3,000 mm. well-diameter with delivery capacities of from 1 to 20 cubic meters per hour. Large models are made to order. Most units are suitable for inland lakes, seaports and inland ports. However, the 3,000 mm. is claimed to be able to operate in 50 cm. (20 inch) waves. Self-propelled vessel types are available. (See Appendix D, Fig. D-18).

2. VORTEX ASSISTED SUCTION DEVICE - Elf Petroleum Company and Bertin Industrial Research Laboratories (France) (Concept)

   A prototype unit has been tested with full scale equipment manufacture being planned. The concept is developed for recovery of spilled materials in harbor or relatively smooth bodies of water. A rapidly rotating propeller, turning in the plane of the water surface and a few feet below it, has been found to produce a cone-shaped pocket. Oil is induced to flow to this pocket where it is then sucked out and processed. The more dense the oil, the deeper is the pocket of oil formed in the vortex. A one-meter diameter propeller is reportedly capable of extracting 7,500 liters of crude oil (25 mm, thick) from a 300 square meter area in 1-1/2 hours (99% removal). For oil thicknesses of 5 to 10 mm. recovery can proceed at 4 cu. meters per hour, the manufacturer states.

3. ESSO RECOVERY - Esso

   The diesel-driven Esso Recovery is a converted LCM with a length of 45 ft. and a beam of 14 ft. It is equipped with a Victor oily water separator and four suction skimmers. The suction skimmers are simply open-ended pipes with a dish-shaped tray arrangement placed such that oily water is collected and then transmitted to the 30 ton per hour separator.

4. AIRLIFT OIL RECOVERY DEVICE - Battelle-Northwest (Concept)

   This device is in the concept development and testing phase under the sponsorship of the FWQA. The work will accomplish testing of an airlift suction device and how the operation of this device may be enhanced by wave suppression equipment and a vortex producing pump.

5. MPCC BUDA I - Marine Pollution Control Corp.

   The BUDA I, a 40' x 10-1/2' vessel with a displacement of 24,000 lb., is said to be easily transported to the site of a spill. Two 25' suction hoses feed a four-tank separator system of 5,600 gallon capacity. The vessel is powered by a 72 hp diesel engine and cruises at 8 mph. A debris catcher is mounted at the bow and the system can be operated by a two-man crew. (See Appendix D, Fig. D-19).

6. SLICKSKIM OIL RECOVERY SYSTEM - Slickbar, Inc.

The Slickskim system comprises a skimmer head, suction hose, hose bridge, pump and discharge hose. The suction head can be made of either aluminum or rubber which floats with the correct orientation reportedly in "rough" water. The hose bridge allows the suction head and the pump to be on opposite sides of a boom, facilitating suction of oil from a boom-contained slick. Model specifications are:

- Model 60 - up to 86 barrels per hour nominal capacity. Complete package including 70' suction and 50' discharge hose (3" I.D.) $3,750.
- Model 160 - up to 254 barrels per hour nominal capacity. Complete package including 70' suction and 50' discharge hose (4" I.D.) $7,450. (See Appendix D, Fig. D-20).

## ROTATING DRUMS OR ENDLESS BELT PICKUP DEVICES

1. FLOATING DISC TYPE OIL SKIMMER - Centri-Spray Corp.

This multiple disc unit is capable of 350 gph of 500 ssu oil at 70° F. or 600 gph of 2500 ssu oil. Scrapers remove the oil from the discs for deposit in oil storage tanks (See Appendix D, Fig. D-21).

2. FLOATING OIL SKIMMER - Surface Separator Systems, Inc.

A rotating cylindrical reinforced plastic surface with a doctor blade removes up to 95% oil from the sea surface. The speed of rotation is quite critical and must be carefully and constantly controlled. The use of multiple cylinders reportedly reduces the sensitivity of control required. Rotation is accomplished by direct drive orbital or planetary geared hydraulic motors. Gasoline, diesel, electric or air prime movers are used as desired. Eleven models are available from 150 gph to 600 gph ranging in price from $3,130 to $9,750 (See Appendix D, Figure D-22).

3. M/V PORT SERVICE - Port of Baltimore

The PORT SERVICE is a vessel equipped with three partially immersed, rotating, retrieval cylinders mounted in the bow of the barge. Retrived oil has less than 5% included water content. The oil wiped from these cylinders by a doctor blade is then transferred by a fourth cylinder to an internal 3,000 gal. holding tank in the body of the barge. During the past few years, this vessel has recovered: diesel fuel, lubricating oils, vegetable oil, and crudes. Recovery rates vary from 200 to 500 gph. This vessel is somewhat sensitive to water roughness. It does, however, provide a solution to spills in harbor or other protected areas where wave heights do not exceed 1 foot. The present cost of a device similar to this barge is approximately $105,000. The charge out rate for the use of this barge in Baltimore Harbor is $100/hr.

4. MOP-CAT - Studebaker - Worthington, Inc.

The mop-cat is a 29 foot long, 12 foot wide catamaran. It can sweep a 15 foot swath and recover oil at 1.2 and 3 knots. It has a 10 knot forward, 4-5 knot reverse and a side thrust capability of 2 knots or more. Power is by two 20 hp vertical propulsion drive modules and 1-10 hp horizontal oil-drum/pump drive.

Propulsion is by water-jet thrusts, designed for shallow water operation. The method of operation is a 12-inch diameter revolving drum of hydrophobically treated polyurethane foam, which sorbs oil. The drum is squeezed free of oil by a metal strip and the oil falls into a catch basin for pumping into a container. Presently a prototype is designed to recover 50 bbl. of oil per hour. It is said to operate on two-foot waves, but the company plans to develop a larger version to operate in six-foot waves. These units will cost about $42,000.

5. RECLAM-ATOR OIL-RECOVERY SYSTEM - Welles Products Corp.

A rotary skimming device is used in conjunction with a small entrance boom. The surface of the roller is covered with a foamed hydrophobic material. As the oil- and water-soaked roller comes around, a secondary roller removes water from the large drum and a small high-pressure roller then removes the oil. Average grade Bunker C can be recovered at rates up to 50 barrels per hour. Pickup capacity increases dramatically with light oils. Wells Products Corporation produces the "Reclam-Ator" skimmer; some models cost less than $11,000. The absorbent surface of the roller can be rendered inoperable by surface debris. (See Appendix D, Fig. D-23 and D-24).

6. OILELVATOR - Bennett International Services, Inc.

A continuous belt of material is circulated from a free-wheeling pivot extended ahead of the bow of a barge to an elevated roller/scraper and back. The belt is a 3 foot width of polypropylene fibre material driven by soft rubber covered steel rolls. The front pivot is maintained in position by flotation and counterweights and as such is responsive to significant wave action. Note the specifications below:

Dimensions - 4'6" height, 4'0" width belt length 12'0" or 2'0"
Drive - 6 hp Kohler gas engine
Weight - 1200 lb.
Capacity - In a 1'0" swell condition

| | gpm | % oil |
|---|---|---|
| Bunker C | 42 | 98 |
| Santa Barbara Crude | 39 | 96 |
| Diesel Oil | 38 | 95 |
| Lub. Oils | 40 | 97 |

A five foot wave, 20 mph wind can be withstood. Belt life of 80-100 hr. One operator can handle the system. (See Appendix D, Fig. D-25).

7. "CENTRI-CLERE" OIL RECOVERY UNIT - Centri Spray Corporation

This unit, installed in an area of tranquil oil accumulation, will remove up to 120 gph of surface oil under continuous operation. Waste oil is removed in a condition that permits resale or reclamation for further industrial application. It has a long vertical orientation and uses a continuous belt and doctor blade (See Appendix D, Fig. D-26).

8. OIL RECOVERY BELT SYSTEM - Shell Oil Laboratory, Netherlands and Murphy Pacific Marine Salvage Company

The "oil scrubber" system uses a sorptive polypropylene continuous hose which continuously travels between two points. Oil is sorbed to the hose as it is moved through the water and squeezed out at the end pulley locations. It is

recommended as a device to control spillage in a canal or waterway. It can be angled to the flow in such a waterway to further increase the booming action of the device. It will contain a storage capability of 1,000 gal. and skimmer pumping capacity of 300 gpm.

Tests September 1969 at Treasure Island (San Francisco Bay) were conducted using 4,000 ssu oil at 50° F and the following belt materials: (1) 5" x 1" polypropylene covered with nylon webbing, (2) 6" x 1/4" polypropylene and (3) 4" x 3/4" polypropylene felt covered with nylon webbing. The system is in the developmental stages (See Appendix D, Fig. D-27).

9. SEA SWEEPER - Wasserbau GmbH (Hamburg, Germany)

In this vessel, designed by Rudolf Harmstorf, a row of belts are mounted on a frame, one end of which extends into the water at an angle. Oil adheres to the belts, is carried aboard and then scraped off and pumped to storage tanks. A 22 hp diesel engine drives the hydraulic system which operates the belts and pumps. The vessel can pick up oil at a maximum rate of 2,100 gph. This device operates effectively only in still waters such as estuaries or harbors.

10. SURFACE SWEEPING SHIP - Mitsubishi Jukogyo Kabushike (Tokyo, Japan)

This patented design uses a flow-through arrangement whereby an inclined conveyor belt sweeps oil and debris aft to a screen collection arrangement for the debris and a doctor blade scraper for the oil. The conveyor helps draw oil into the skimmer and promotes forward motion of the barge. A Vee-boom arrangement is used to contain and condense the slick.

11. MARINE SCAVENGER - Aquatic Control Corp.

The model 258-II kelp harvester has a high capacity for harvesting surface or rooted aquatic plants. Though not designed or even used specifically for oiled sorbent or gellant wastes, this system can load up to 2,000 lb. per minute, wholly operated by one man. Twenty acres per day can be cleared. Units are available with holding capacities of from 2 to 30 tons. For unloading, the conveyor system is raised, the conveyor reversed and unloading occurs at double the harvesting speed. This equipment is not described as an ocean tried system and its seaworthiness is unknown (See Appendix D, Fig. D-28).

12. SURFACE OIL PICKUP (SOP) - Ocean Design Engineering Corp. (Concept)

Ocean Design plans to develop a method of slick retrieval by means of soaking up the surface oil with chips of urethane. The chips are sprayed in front of the 30-foot catamaran. Booms on each side funnel the chips to a conveyor belt, which takes them to a compression unit. There the oil is squeezed out to be stored in the twin hulls, and the chips are recirculated through the U shaped tube and discharged from the underside slot. Ocean Design states it is designed to operate in waves of five feet and winds of 20 mph. The booms and conveyor belt are hinged to retract so that the (SOP) device can pilot to the slick at 10 mph. The craft's capacity is 30,000 gallons and it will be able to sweep an area 80 feet wide and recover 60,000 gph. Larger booms and belts may be attached to the sides of tugs or tankers, the firm states (See Appendix D, Fig. D-29).

13. OIL RECOVERY VESSEL - Oswald Hardie (Manchester, England)

Mr. Hardie, Chief Engineer of the Port of Manchester, has designed a sorbent pickup device which can handle 2 tons of oil per hour. Long rolls of Mutton cloth or paper are passed through the water surface and recovered on rollers. The cloth or paper contacts the oil at the water line and absorbs as much as 5 times its weight in oil. The oil-contaminated rolls are stored and subsequently disposed of by landfill or burning. The oil recovery vessel is 40 feet long and would cost about $48,000 (U.S.) (See Appendix D, Fig. D-30).

SKIMMING WITH A WEIR

1. NORFOLK SKIMMER - Norfolk Naval Shipyard

The Norfolk skimmer barge is 12 feet wide, 25 feet long, 3 feet 2 inches deep and has large holes in the bottom for free passage of water. The top portion of the barge contains air flotation cells, which support the skimmer with approximately 18 inches of freeboard. The tank section of the barge extends 5 feet 4 inches below the flotation cells and has a capacity of 10,000 gallons. Under the air cells, there is a small diffusion box with numerous holes, into which the surface oil and water is drawn. Here, the oil and water separate by gravity, the water passing out the bottom, the oil remaining in the barge. A metal sump, fitted at one end of the barge, is used to draw the surface oil and water to the skimmer. The lip is adjusted to just below the water level. The bottom is fitted with a 6 inch connection pipe leading to a 65,000 gph centrifugal pump. The lip or dam and the draw down effect combine to facilitate the oil drawing action of the skimmer. This method is so successful, that this skimmer is permanently located drawing oil from nearby harbor facilities and from relatively inaccessible locations. Fire hoses and work boat propellers induce movement of slicks from greater distances. Skimming with this device can be accomplished at 600 gph (oil) at a cost of from 1 to 5 cents per gallon of oil. The skimmer cost approximately $10,000. It is not expected that this skimmer would operate efficiently in open sea conditions.

2. SPILLED OIL SKIMMING VESSEL - The French Technocean Company (Concept)

Experimental efforts with ship models is being undertaken by Technocean. The ship is to have a normal, rather blunt bow but will split into a catamaran-like, twin-hull formation from amidships to the stern. The space between these two hulls is expected to form an area of much attenuated wave characteristics. For the operational mode the vessel will move slowly in the reverse direction, skimming oil through a 33 foot intake valve at the point of the V of the twin hulls. The intake valve will adjust automatically to the level of the surface. The main and secondary screws will be operated to allow good manuverability. The ship is designed to treat 13,000 cu. yards of water per hour and to store an equal volume of oil waste. Draconi barges are also carried, each capable of 1,300 cu. yards of filtered oil. The system can be deployed to the scene of a spill at 15 knots and may be used for oceanographic research functions when not in use for oil spillage control (See Appendix D, Fig. D-31).

3. T-T RECOVERY UNIT - Trygve Thune A/S (Oslo, Norway)

This recovery unit is basically a paddle wheel supported on pontoons with trimming device, separating chamber and oil receiver attached. The wheel reaches 10 cm. into the water and guides the liquid into the separating chamber. The chamber has a perforated bottom which allows the water to escape while the oil rises and overflows into an oil receiver. T-T oil booms are attached to the bow of this device to increase the effective surface area skimmed and to facilitate the movement of an enclosed oil slick to the skimmer.

4. SPILL FIGHTER - Trelleborg Rubber Co., Inc. (Concept)

"Spill Fighter" is to be built to user's requirements with oil carrying capacities from 2 tons, or more. The smallest unit, C-2, will have an oil skimming capacity of 1.6 cu. meters per hour (10 bbl per hour), water treating capacity of 100 cu. meters per hour, and will be able to operate in two foot swells. Spill Fighter is designed as a surface traversing unit with fixed rigid vee booms, also suited for attachment of additional oil booms. Water and oil will flow over the front weir into a coalescing area where the surface oil is skimmed to a settling tank. Water settling from this oil is then released back to the coalescing chamber. Water is released from the area by an underflow inverted weir, then past an overflow weir. A sump at this point produces the impetus for the water outflow. It is brought about by appropriate placement of the outboard engine such that it draws down the water level in this sump. Prices are from $18,000.

5. "SLICKSLED" - Water Pollution Controls, Inc.

The "Slicksled" is comprised of a simple, inverted column of water open to the sea at the bottom, supported by pontoons. The entrance to the raised column is an inclined, horizontal funnel, which permits the craft to skim the undisturbed surface of the oil. The oil raises to the top of the inverted column, displacing water at the open bottom. After sufficient oil has accumulated, it is pumped to a support barge or storage receptacle. It is estimated that a 14 foot prototype can collect 1,000 gph at a speed of 5 knots from an oil of 1/16 inch.

6. WATERWISSER - Shell Oil Company

This 47 foot self-propelled barge has attached Vee booms in front making an effective 65 foot sweep. The barge moves at less than 2 mph. Oil is sucked from the water surface through a vertical slot extending below the surface. The recovered oil is decanted with the water pumped overboard. It has a storage capacity of 20 tons and a water return pumping capacity of 100 tons per hour.

7. SIDE BOOM SKIMMER - Union Oil Company

The Union Oil Company used a side boom skimmer of their own design during the Santa Barbara Channel Incident (See Appendix D, Figure D-32). This device was installed on the MV WINN. Two self-priming, high capacity centrifugal pumps were employed to transfer the oil through six-inch diameter lines from the skimmer to on-board storage tanks. These pumps were capable of alternately pumping either air or water containing a considerable amount of solids. Each pump had a capacity of about 700 gpm and was equipped with a vacuum assist system for self-priming. The oil recovery apparatus consisted of an adjustable trough mounted transversely between two steel flotation cylinders in an open "V" configuration. The cylinders were approximately 26 inches in diameter and

20 feet long. The opening of the "V" was approximately 20 feet. The trough, ten feet long and 8 inches wide, was in the form of a "J" with the lower lip facing the direction of advance. The oil-water mixture, after entering the trough over the leading edge, was pumped from the bottom of the trough through one of two 6-inch lines. It was estimated that this device, as designed, would recover a 19:1 water to oil mixture. Two 17,500 gallon ship tanks were employed; one for holdup and decanting, and the other for storage of the oil-water emulsion. The mixture was held in the decanting tank approximately 30 minutes before transfer to the storage tank.

This skimming device proved relatively effective while advancing at speeds up to five knots. It was the only skimmer used that was capable of traversing slicks and recovering the "ropes" of oil formed by wind and wave forces and which extended for considerable distances. It was also successfully employed to skim the oil held up by kelp beds near shore. The capacity of the skimmer under ideal conditions and working in a relatively thick slick was about 25 barrels per day.

Skimming operations were not pratical in winds exceeding 15 knots. Rough seas prevented operation on many occasions. The centrifugal pumps tended to emulsify the oil during each transfer operation and severe problems often were encountered offloading the oil to receiving trucks after the oil had been transferred between tanks at sea. A water-in-oil emulsion was formed with the approximate consistency of light grease after two transfer operations with centrifugal pumps. Chemical demulsifiers were occasionally necessary to achieve transfer.

## AUXILIARY EQUIPMENT

1. COALESCENT OIL-WATER SEPARATOR - Aqua. Chem.

This separator is capable of separating oil from water and insuring that the water discharged contains less than 100 ppm oil at any inlet concentration level up to 100% oil. The Coalescent oil-water separator is designed to separate oil with specific gravities less than 0.985. The pressure drop is relatively low and is operated from 30 psig at the inlet to 20 psig at the discharge. Standard sizes range from 50 gpm to 1,000 gpm with higher capacity separators furnished by special order. The coalescing element life is found from testing with various oils and concentrations to be in excess of 250,000 gallons per element (6 elements). It is also designed to function effectively on mechanically produced emulsions such as those produced by pumping. (See Appendix D, Fig. D-33).

2. VORAXIAL OIL SEPARATION SYSTEM - Reynolds Submarine Services Corp. (Concept)

The device, which will use a combination of gravity and acceleration, partial pressure and vortex axial flow, is in the prototype stage of development. It is planned that oil and water rapidly rotating in a pipe will concentrate oil at the center and water in the outside annulus. A concentric tube to collect the oil is located within this pipe. Flow rates of water and oil phases are controlled in order to optimize system performance. A single 8 inch diameter pump will take in 2,500 gpm. A 100 hp diesel-engine hydraulic drive system is specified. Assuming an oil delivery rate of 10%, this pump would be able to separate 250 gpm of

salvageable crude oil. Light-weight versions for air deployment may be developed according to the manufacturer. A cost of $111,200 and a 6 month delivery period is estimated for the VORAXIAL separator system which would include two weeks of demonstration/performance qualification testing.

3. UNIVAC PUMPS - Henry Sykes, Ltd. (London, England)

The characteristics of Univac pumps are said to be particularly suitable for suction skimming. They can operate with branched suction hoses intermittently exposed to air and of lengths up to 400 yd. They also have the ability to pass solids up to 4 inches in diameter and thick sludges of high viscosity. Univac pumps can be mounted on small coastal type tankers. A tanker of this sort carrying 6 Univac UVC6 pumps (50,000 gph) would be able to handle 75,000 gph of oil/water mixture, allowing 25% efficiency for air entrainment. If 10% oil were present, 7,500 gph could be collected. These pumps with appropriate skimming intakes and other equipment would function in a contained spill pickup or in a suction skimmer mode.

4. OIL/WATER SEPARATOR SYSTEM - Garrett AiResearch Manufacturing Company

The Garrett separator system was developed under contract to the FWQA and is presently being used in the prototype unit under test by the American Petroleum Institutes' project, "Seadragon".

The system operates on a centrifugal system which has the following operational characteristics: (1) operates in open waters during Sea State 7 and at temperatures between 28° and 90° F., (2) processes oil having an API gravity range of 10 to 60 degrees, (3) is available to workboats or similar devices (75 square feet), (4) air transportable (weighs 2 tons), (5) processes 30,000 gal/hr. of gross liquid, (6) separates oil and water regardless of dispersion or emulsion type, (7) processes water to less than 100 ppm and (8) salvages oil-water mixtures to less than 5% seawater content.

# APPENDIX D

## PHOTOGRAPHS AND DRAWINGS OF TYPICAL SYSTEMS AND EQUIPMENT

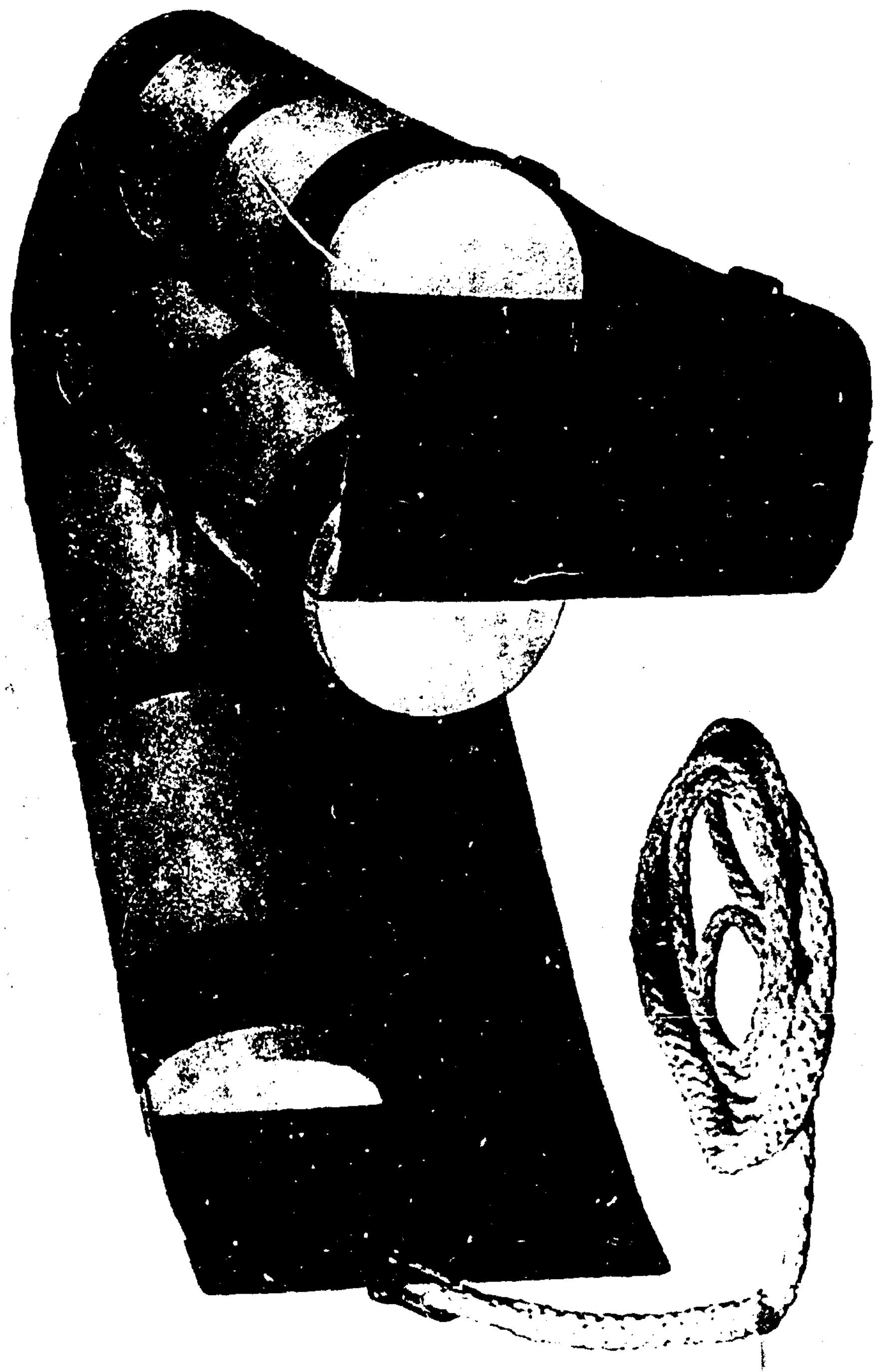


Figure D-1 Slickbar boom produced by Slickbar Inc.

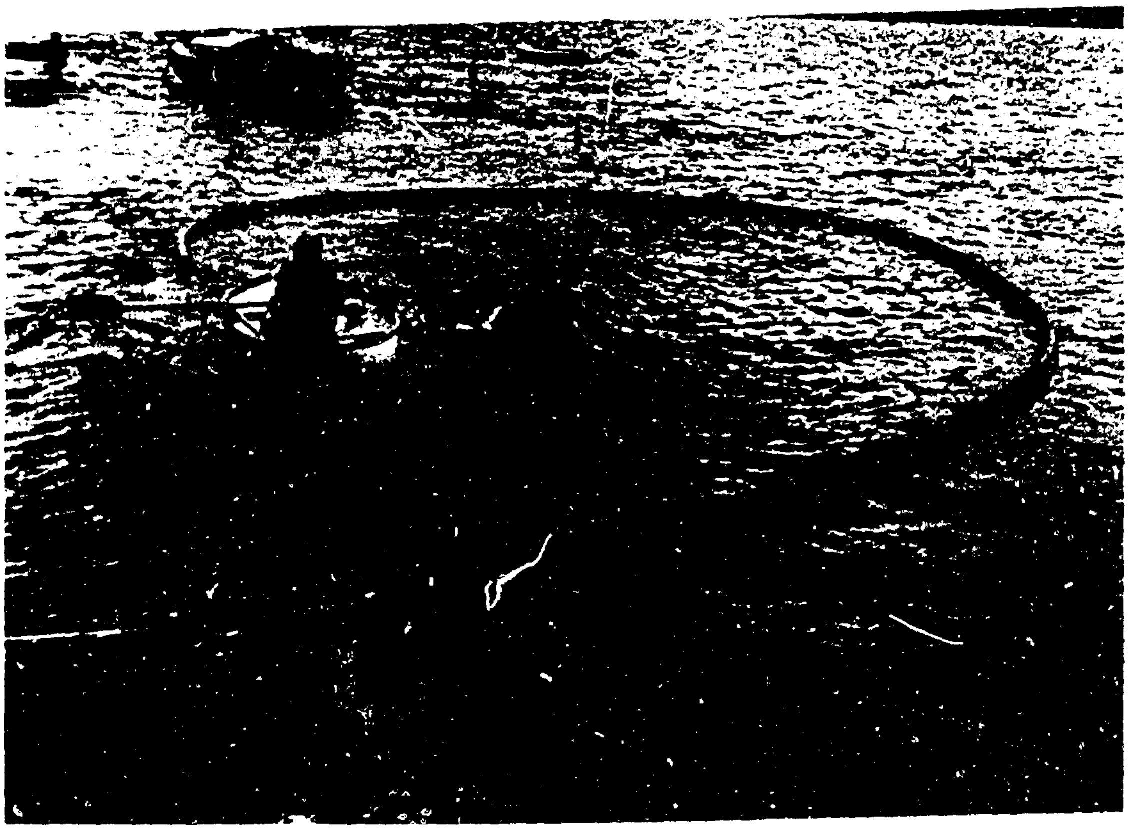


Figure D-2 SOS boom distributed by
Surface Separator Systems

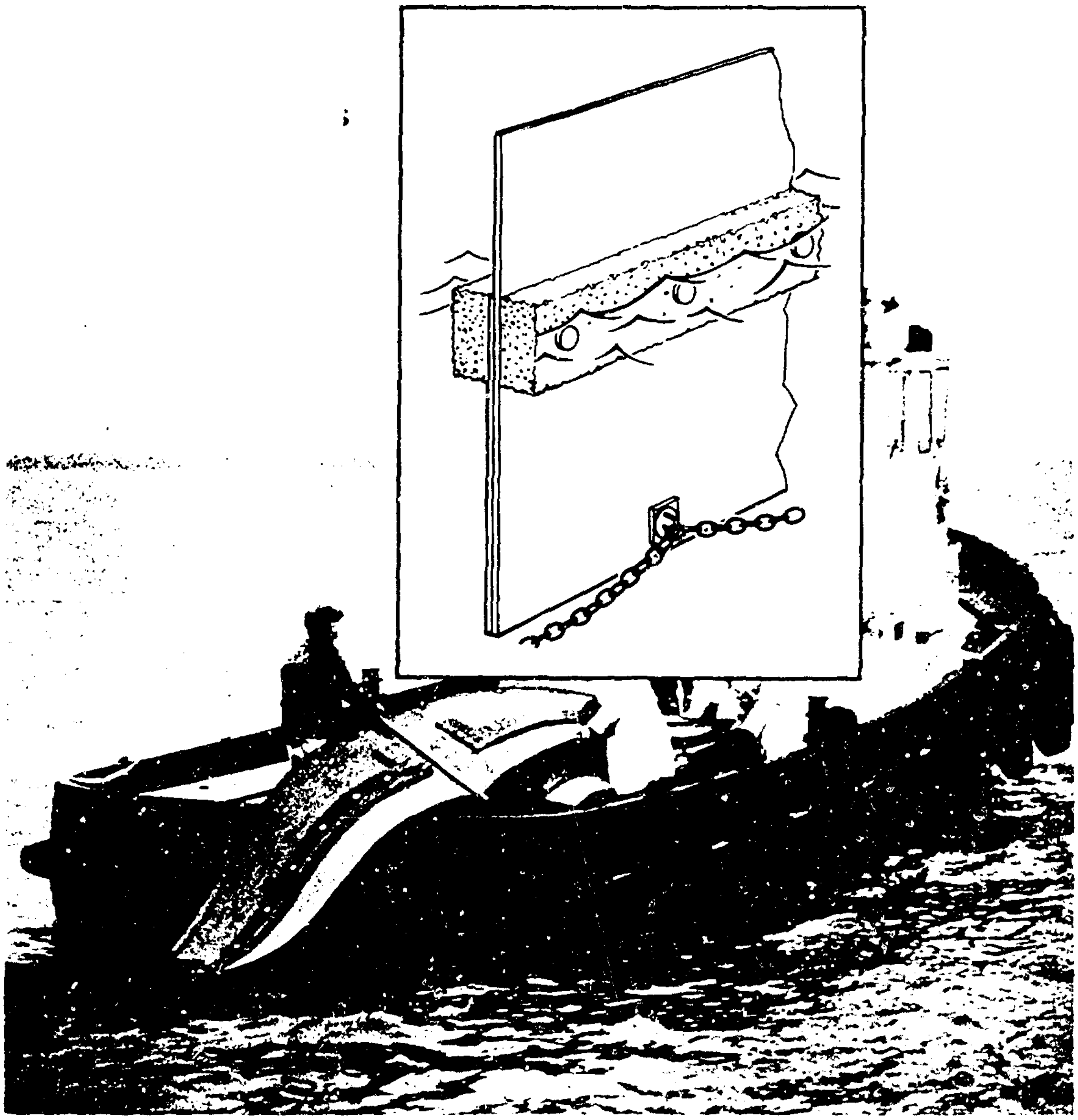


Figure D-3 Spillguard boom
produced by Johns-Manville

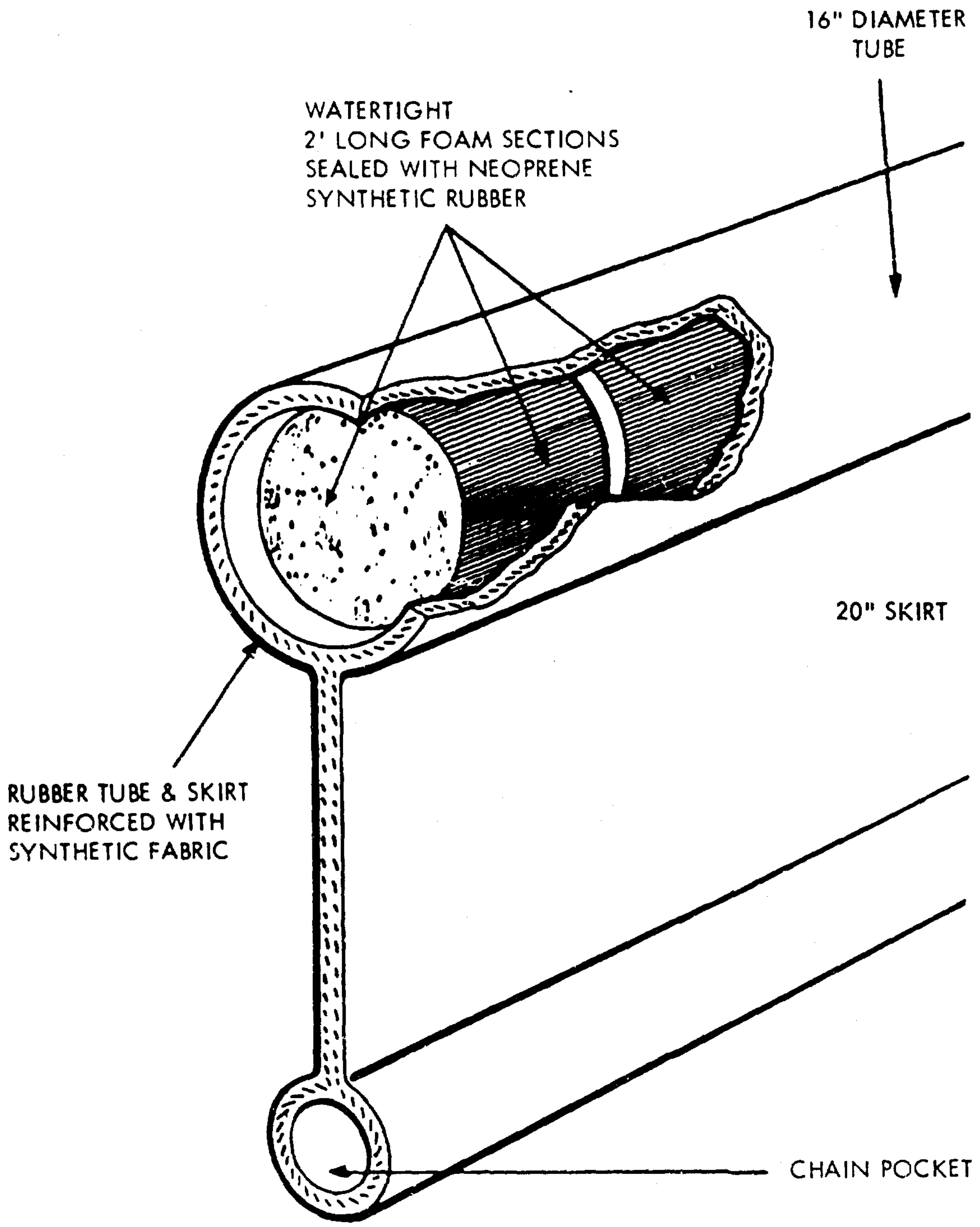



Figure D-4 Warne foam-filled boom
produced by William Warne & Co., Ltd.

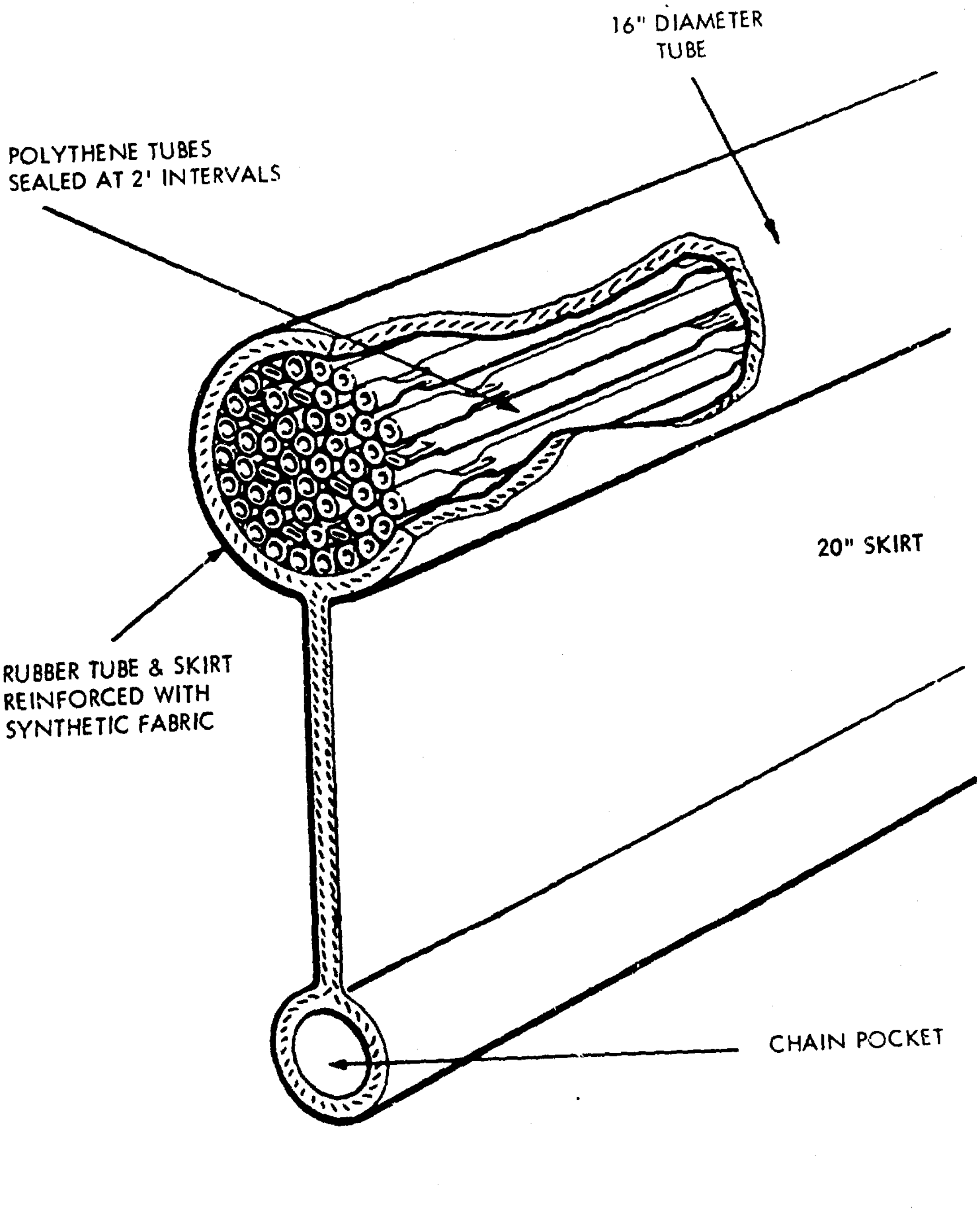



**Figure D-5 Warne tube-filled boom produced by William Warne & Co., Ltd.**

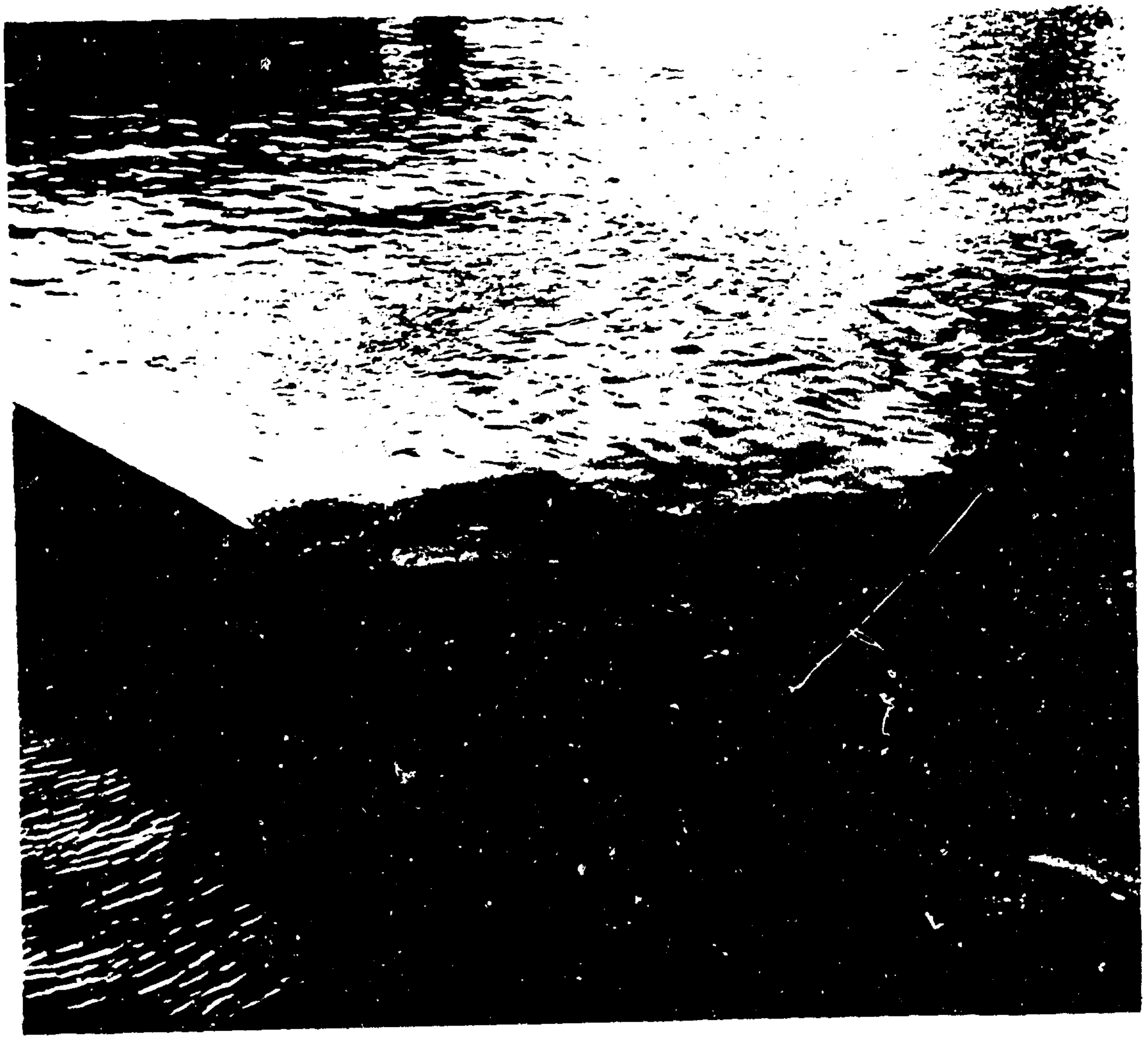


Figure D-6 Warne inflatable boom in operation produced by William Warne & Co. Ltd.

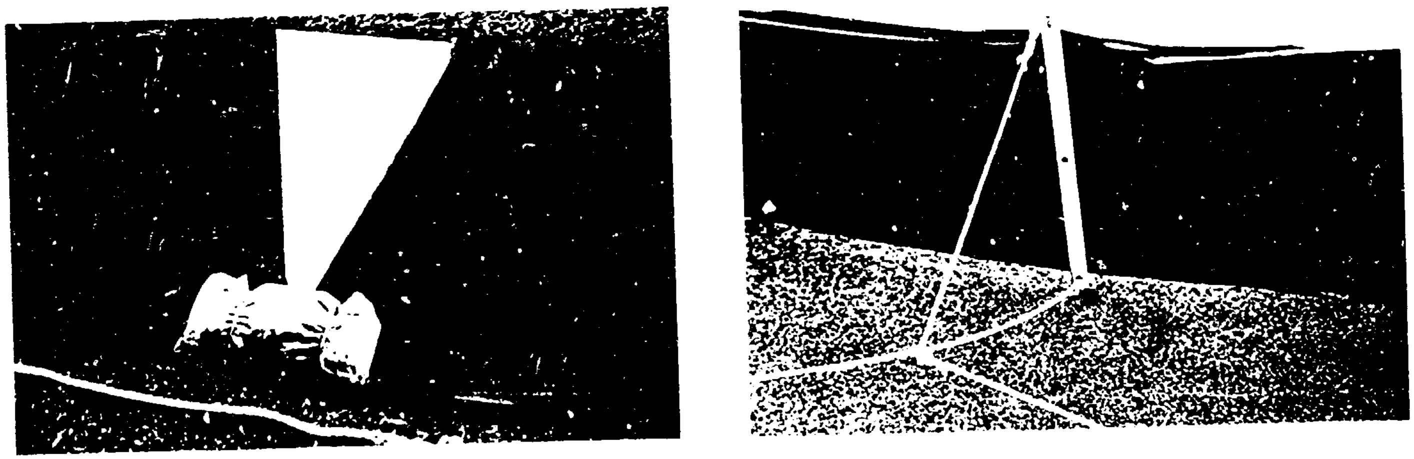


Figure D-7 Rode ORM (red eel) produced by Trelleborg Rubber Co., Inc.

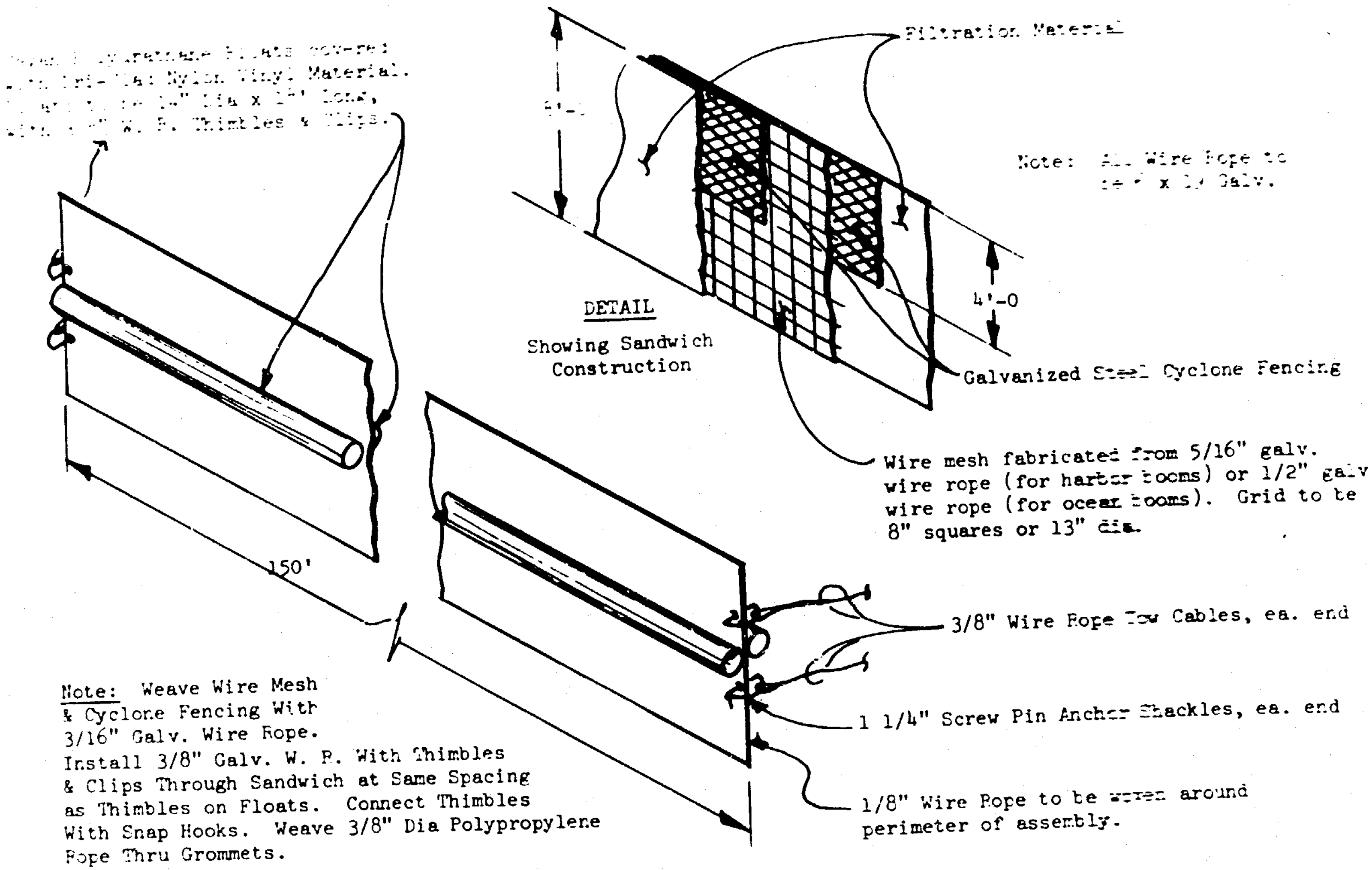



**Figure D-8 Kain offshore filtration boom produced by Starcross Oklahoma, Inc.**

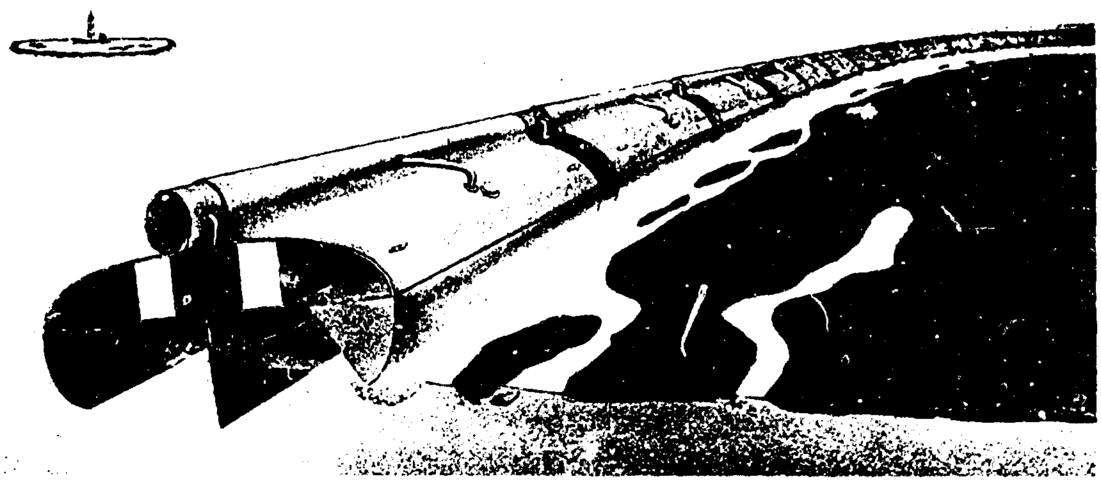


Figure D-9 Oscarseal system produced by The Rath Company

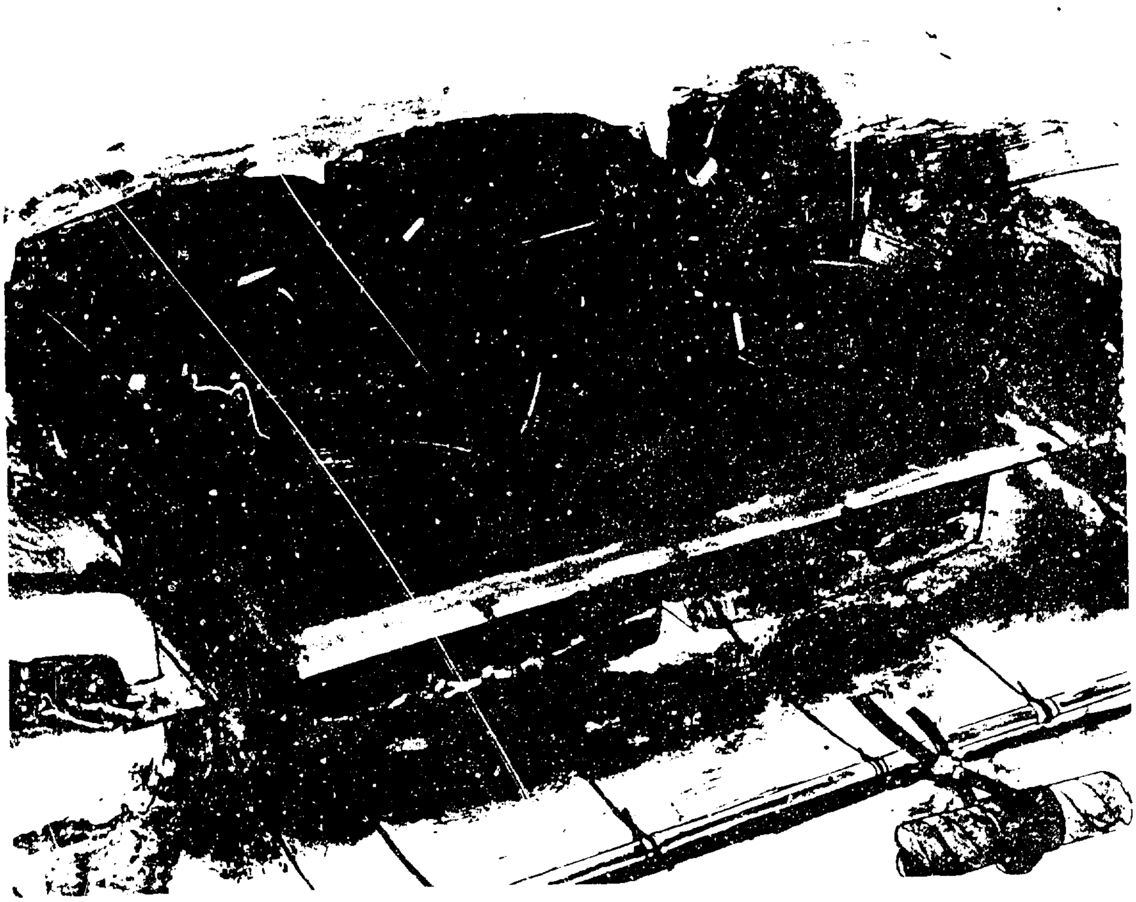
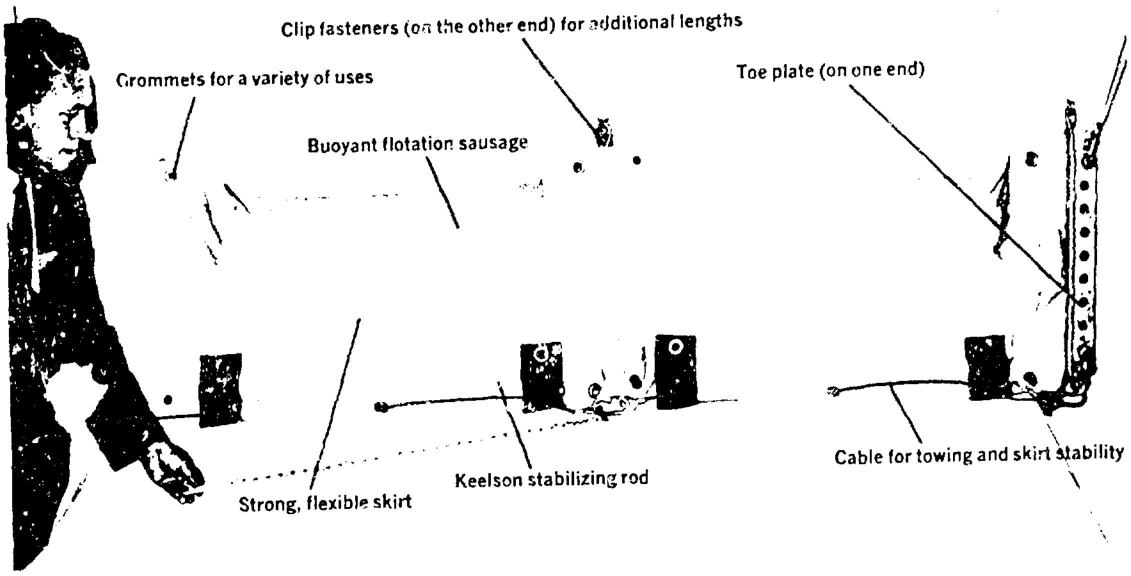


Figure D-10 Conway retainer wall produced by Offshore Safety Systems Inc.



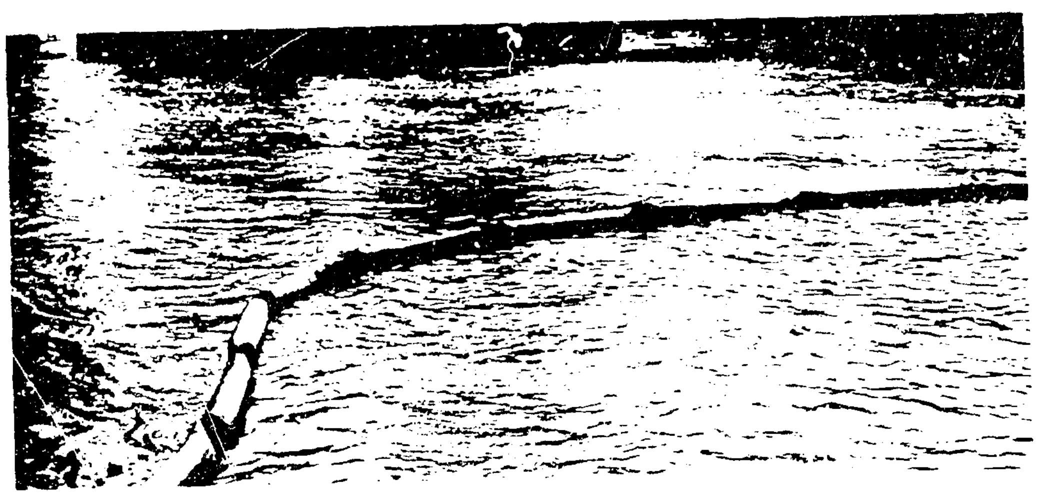



Figure D-11 MP boom produced by
Metropolitan Petroleum Petrochemicals Company, Inc.

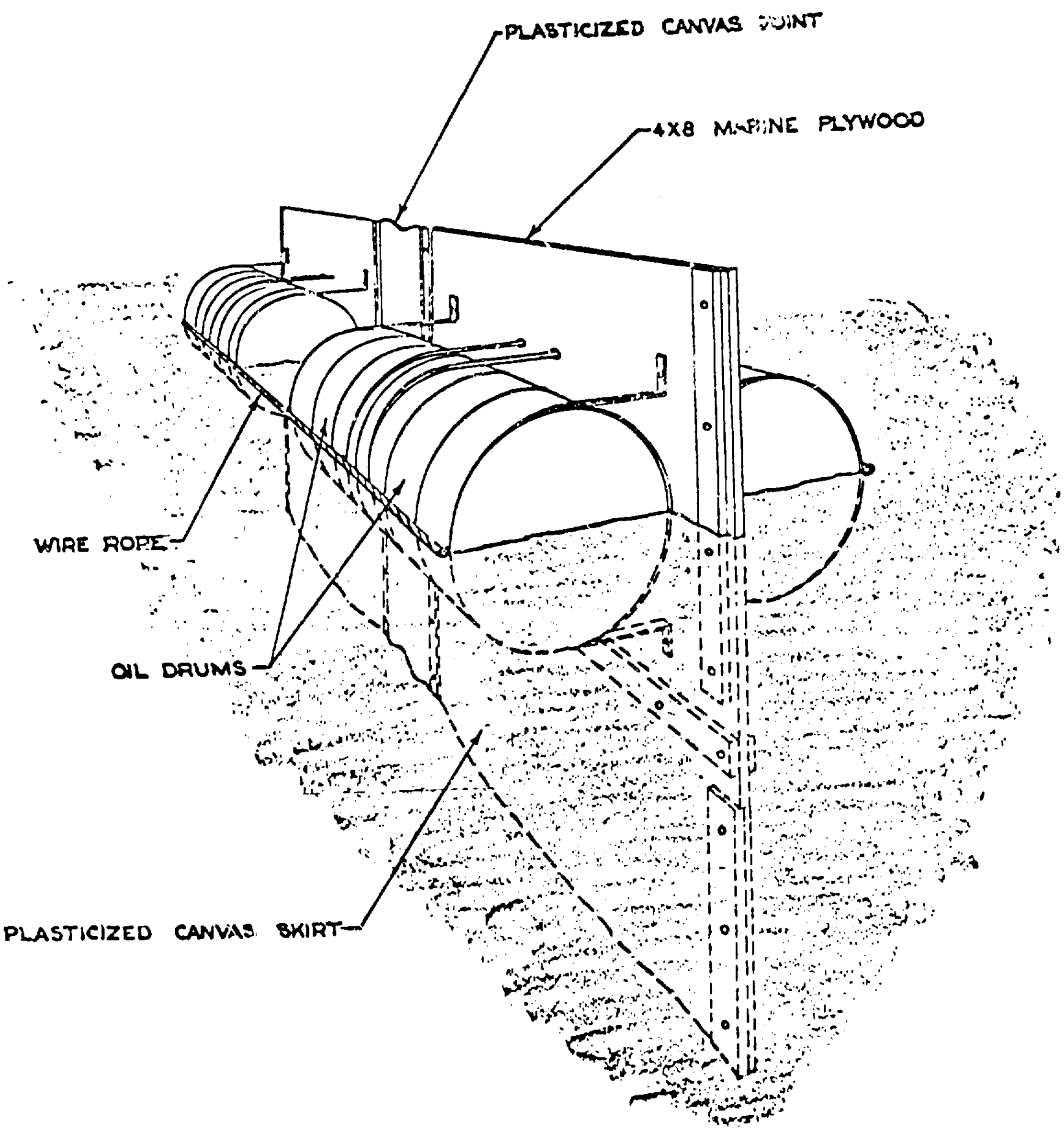
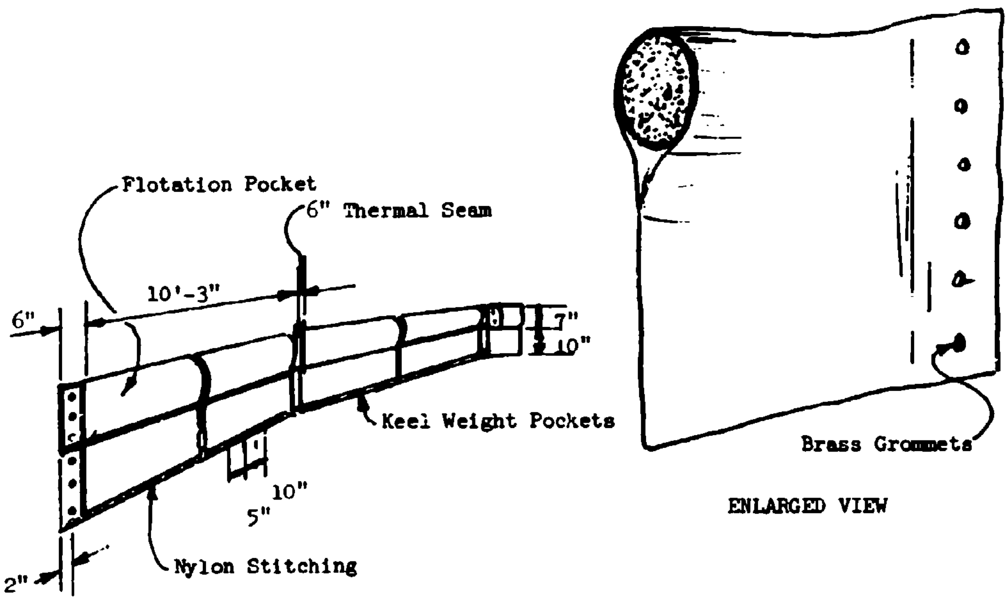



Figure D-12 Navy heavy duty oil pollution containment boom produced by Murphy Pacific Marine Salvage Company




Flotation Pocket Contains 4"x 9' Dow Ethafoam Cylinder.
Keel Weights are 3/8"x 4" Hot Dipped Galvanized Rods.

**Figure D-13 Jaton floating oil retainer produced by Centri Spray Corp.**

Figure D-14 Muletex boom produced by Muehleison Manufacturing Company

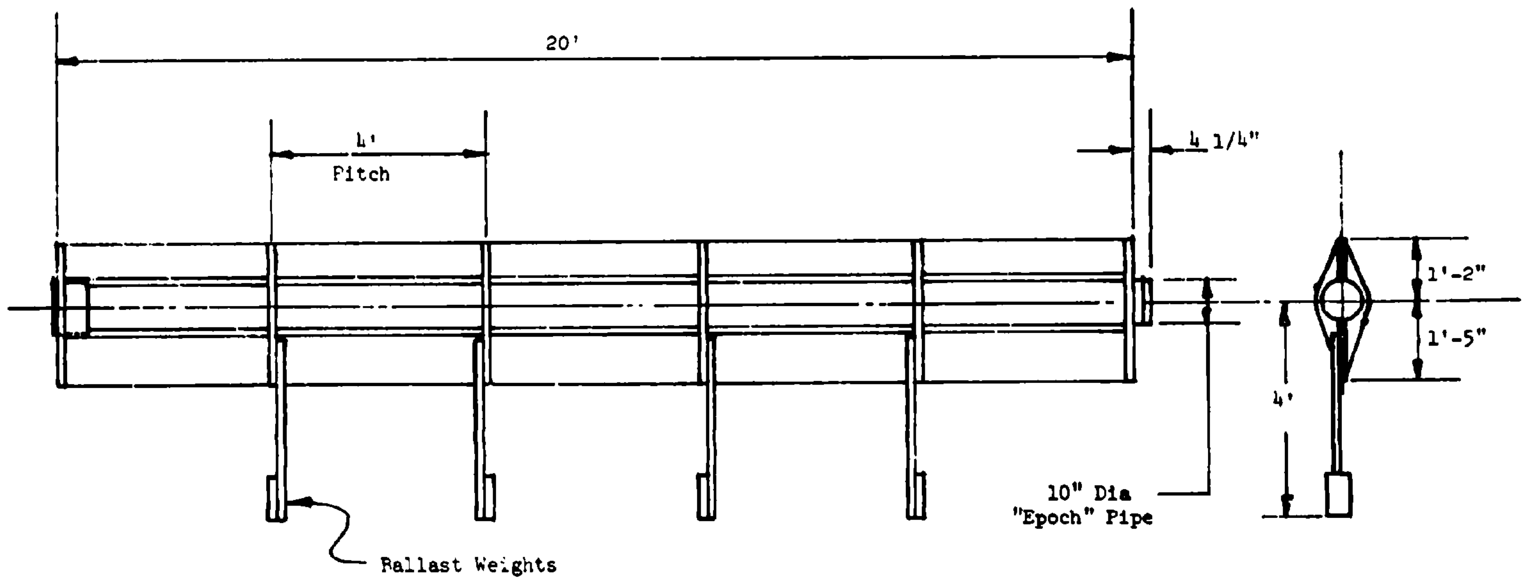



Figure D-15 Bristol floating boom
produced by Rolls-Royce, Limited

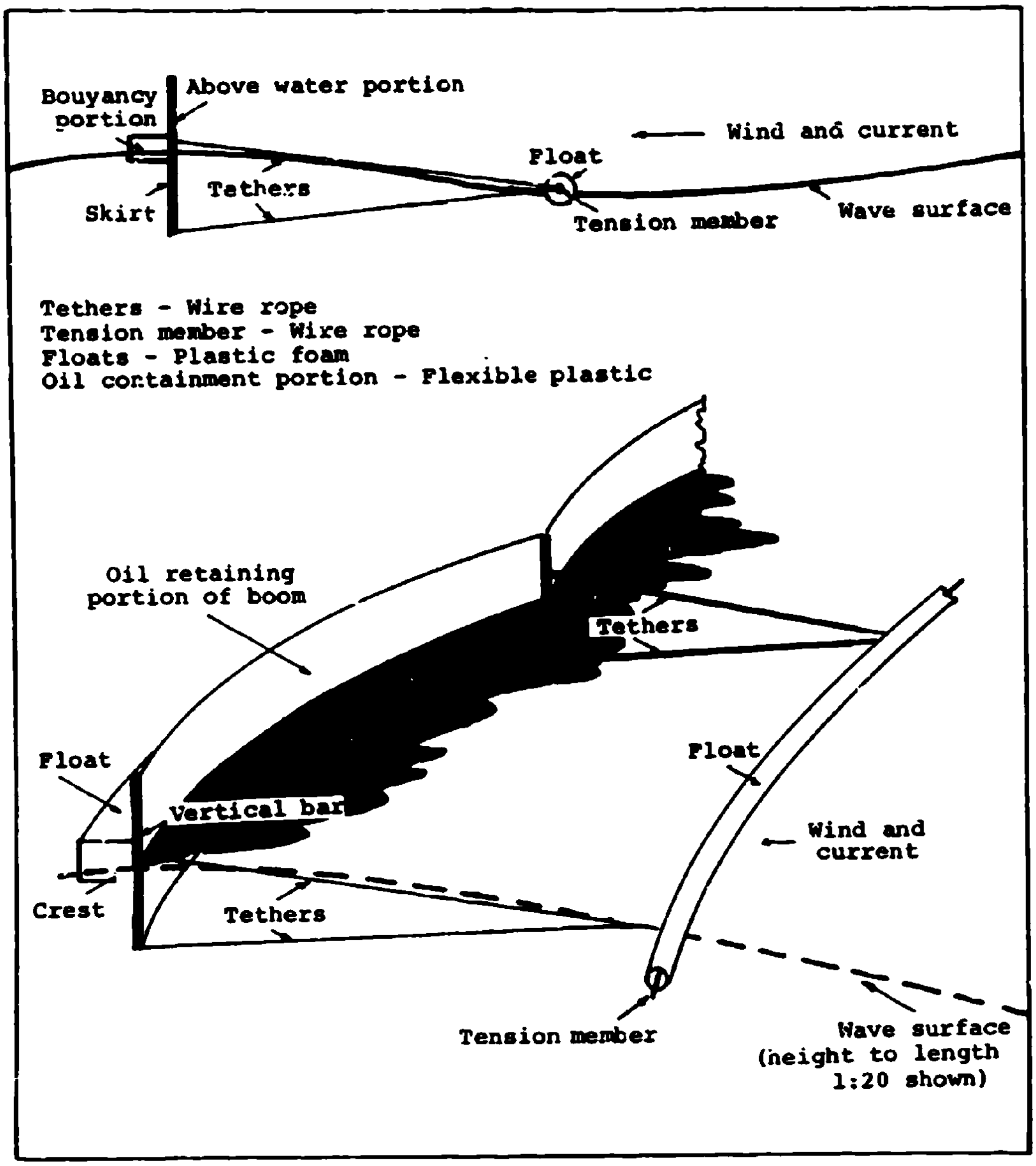



**Figure D-16 Rough water containment system under development by Deepsea Ventures, Inc.**

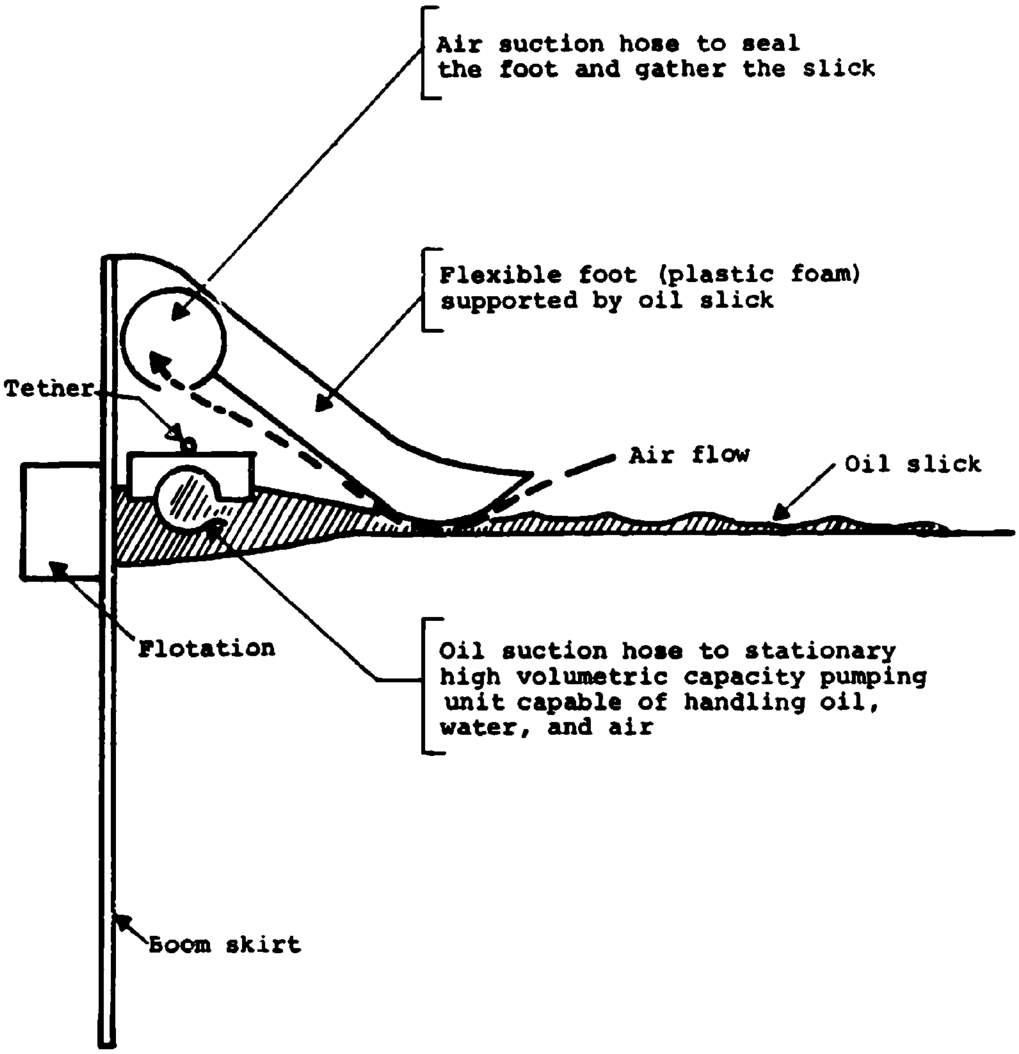



**Figure D-17 Rough water oil containment system under development by Deepsea Ventures, Inc.**

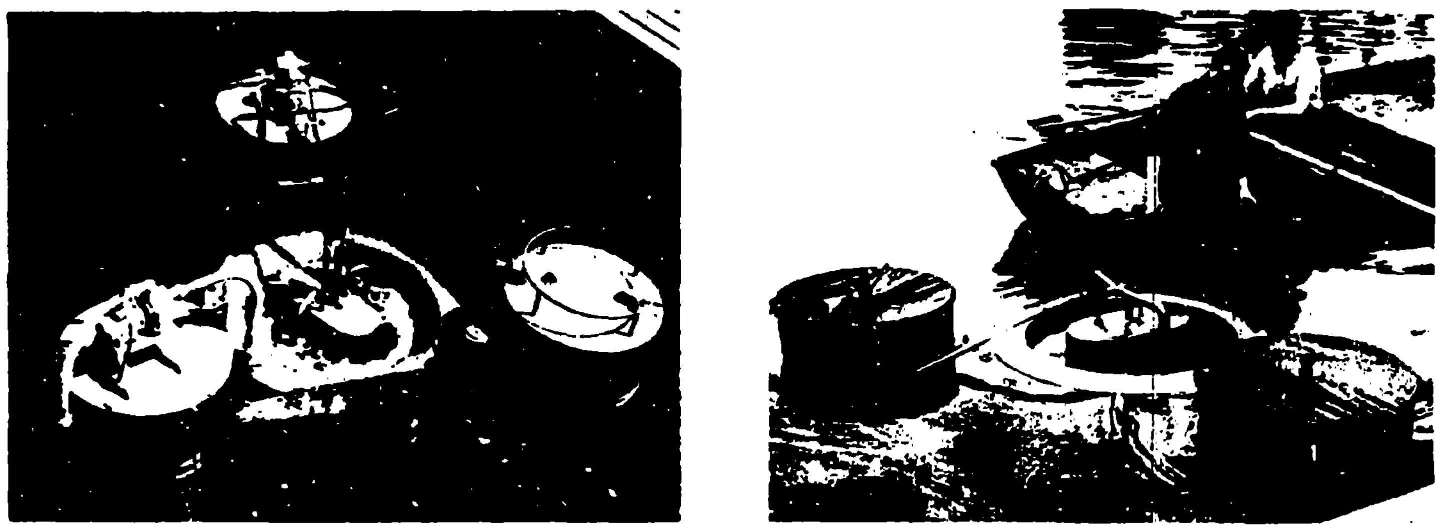


Figure D-18 Rheinwerft oil removal units produced by C. A. Belcher Ldt. ( London, England )


Figure D-19 MPCC BUDA I
produced by Marine Pollution Control Corporation

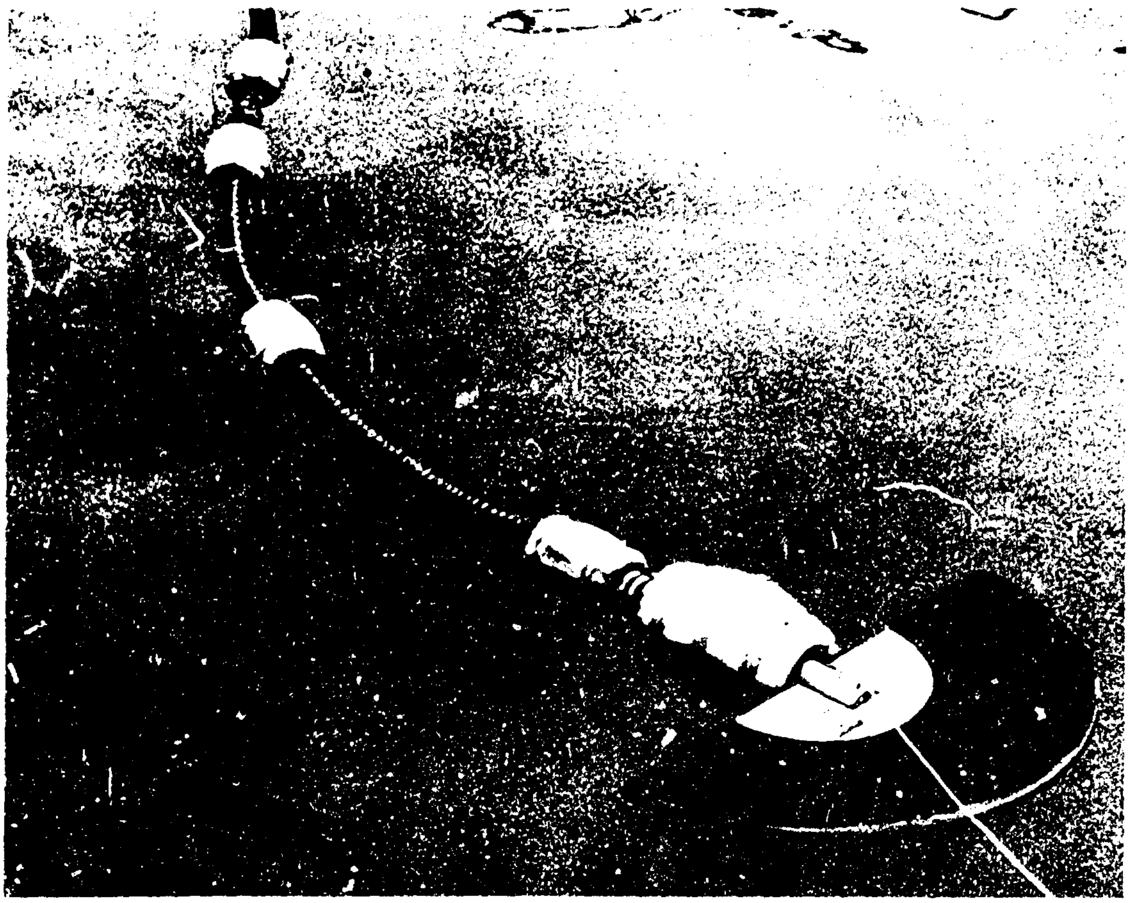


Figure D-20 Floating suction head
produced by Slickbar, Inc.

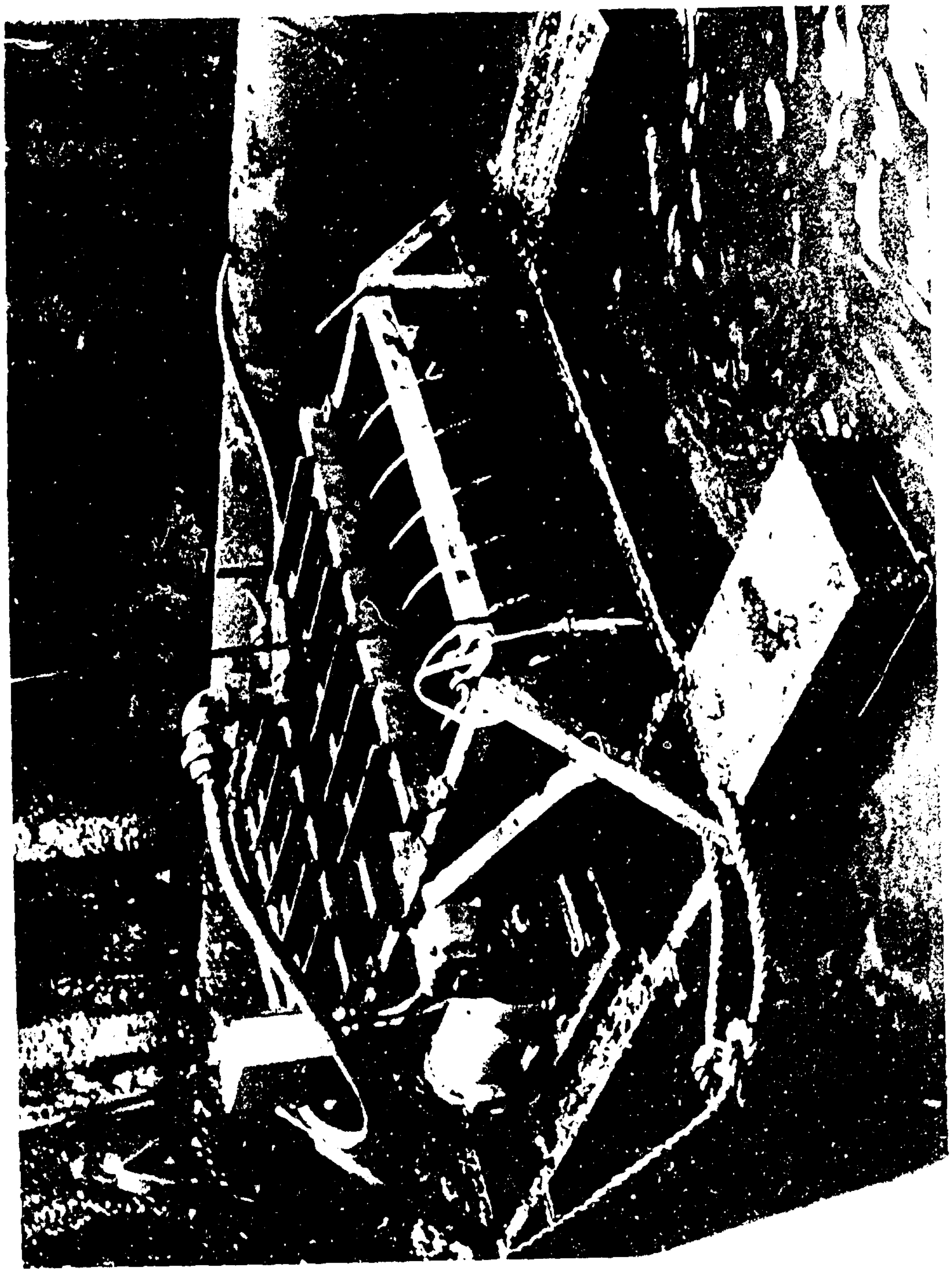


Figure D-21 Floating disc type oil skimmer produced by Centri-spray Corp.

Figure D-22 Fixed oil skimmer, model BD-213 produced by Surface Separator Systems, Inc.

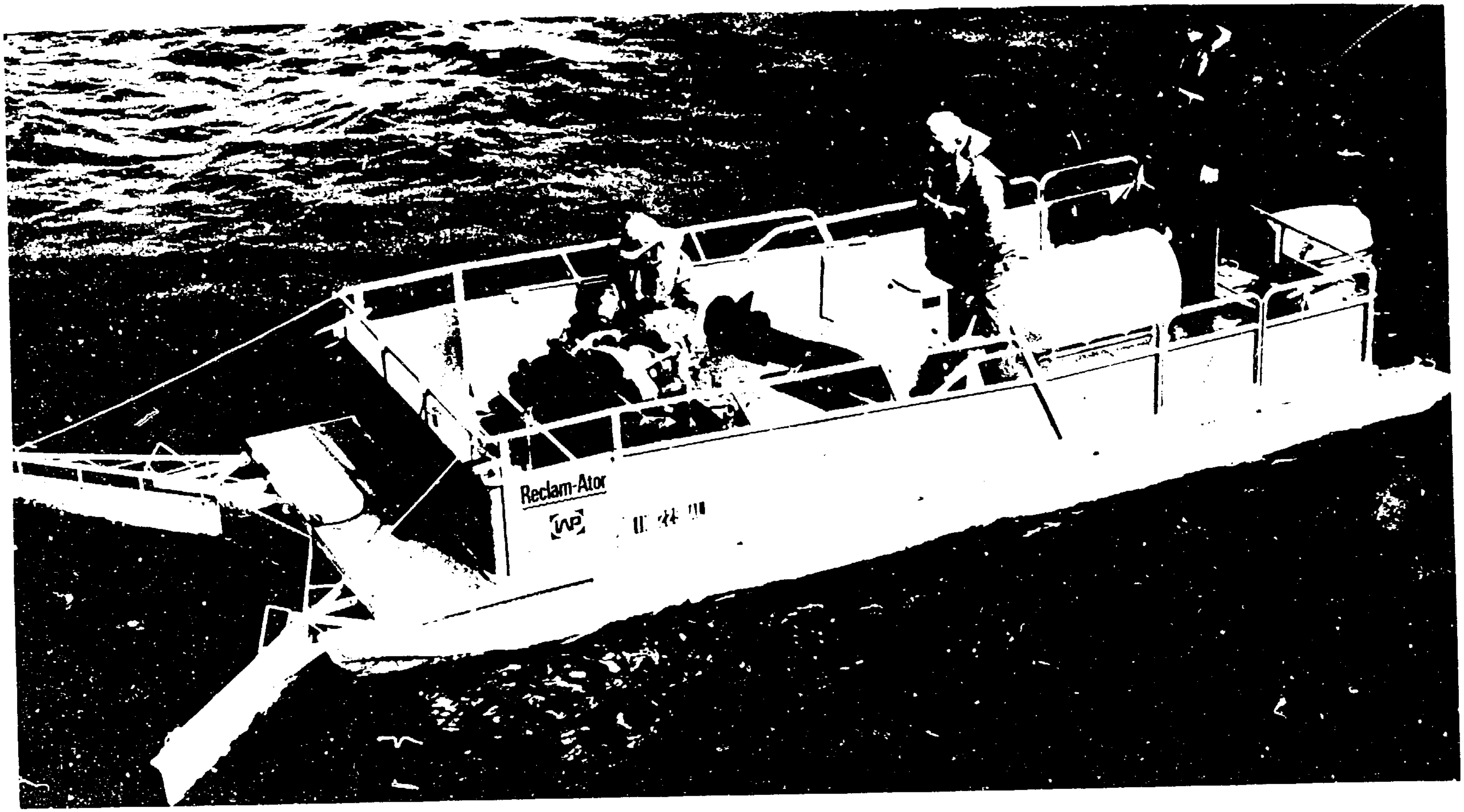



Figure D-23 "Reclam-ator" skimmer
produced by Wells Products

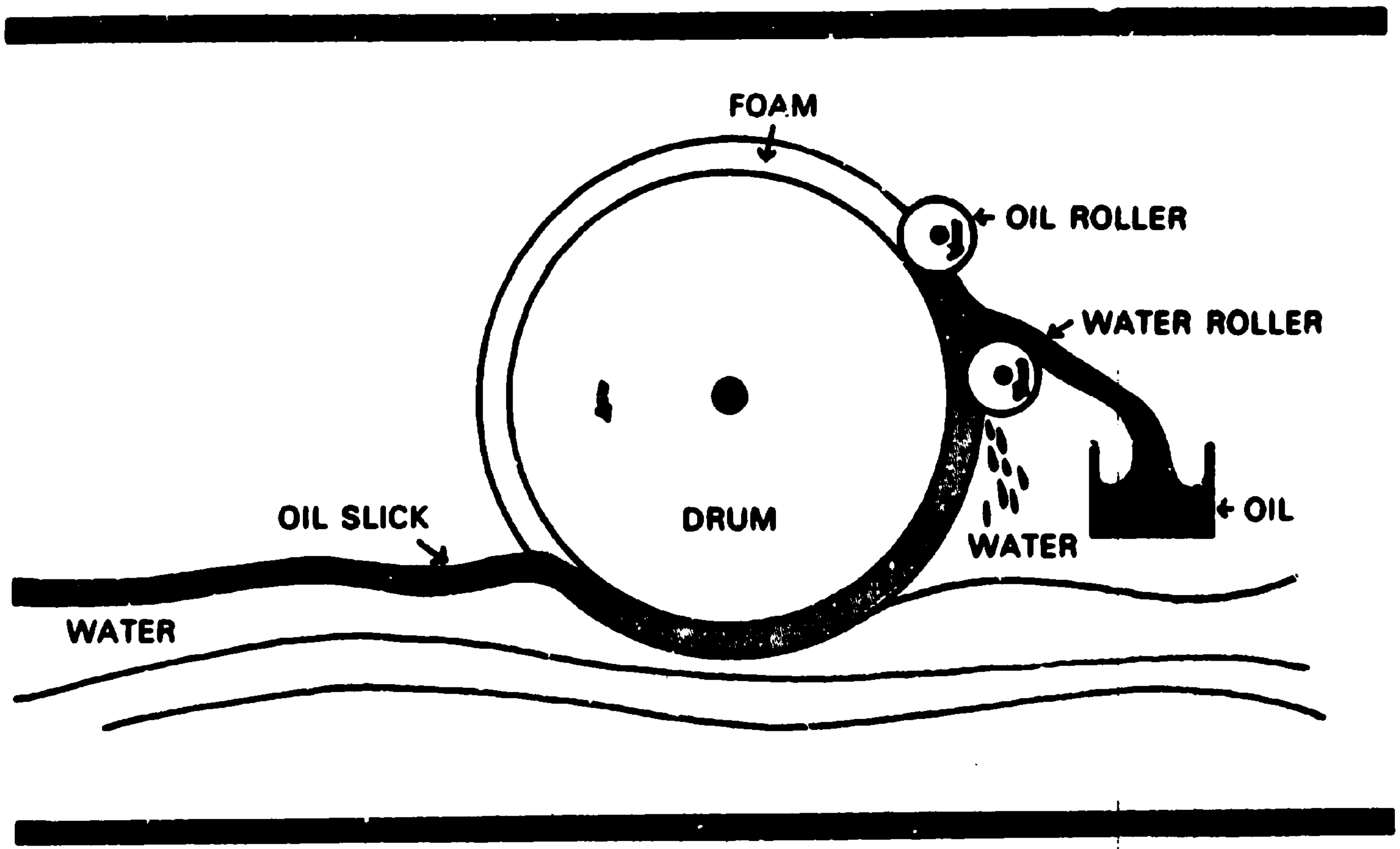



Figure D-24 "Reclam-ator" roll skimming mechanism

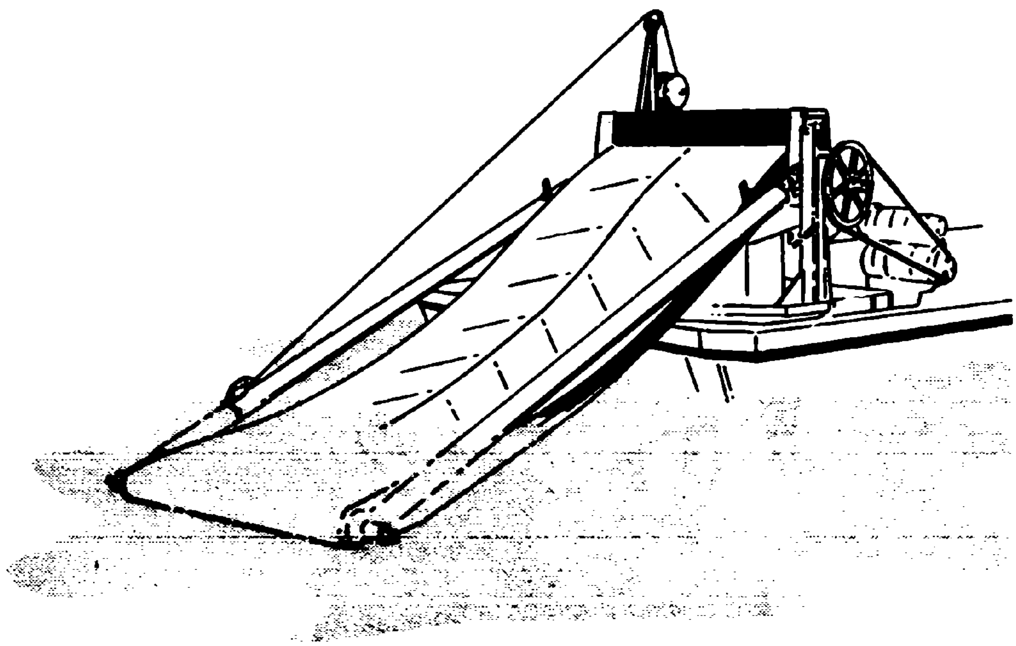


Figure D-25 Oilevator Produced by
Bennett International, Inc.

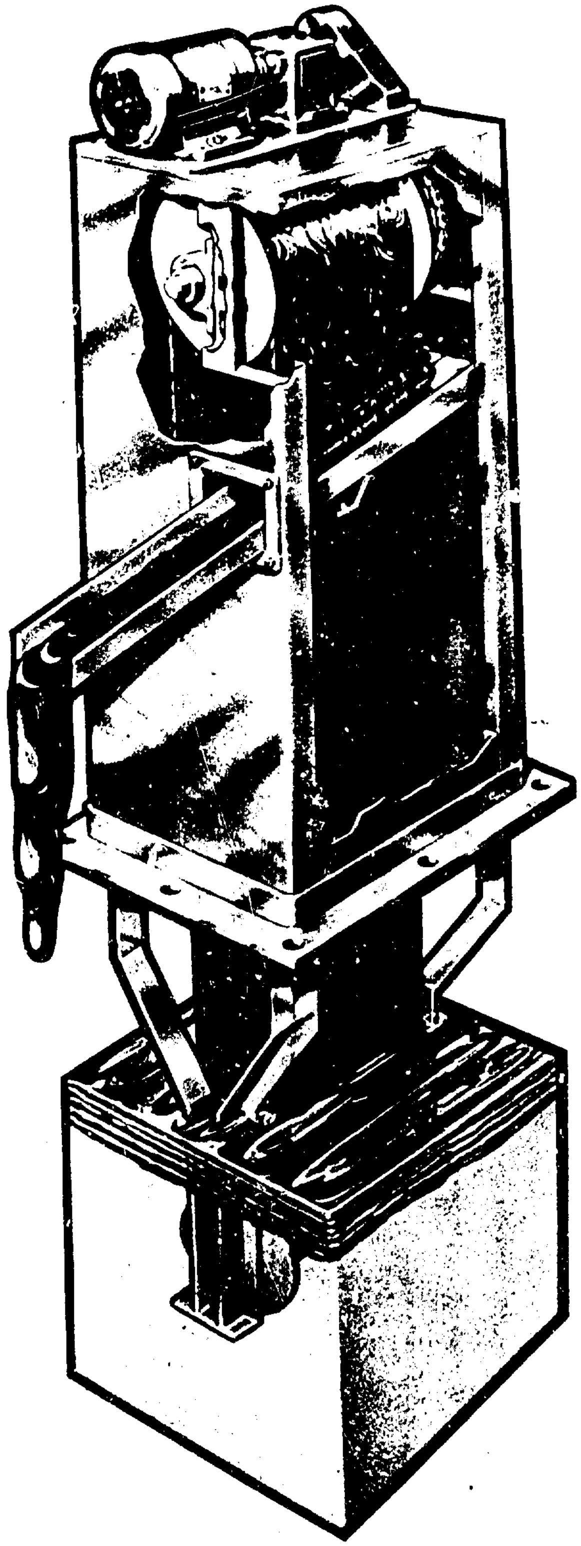


Figure D-26 Centri-spray unit recovery
produced by Centri-spray Corp.

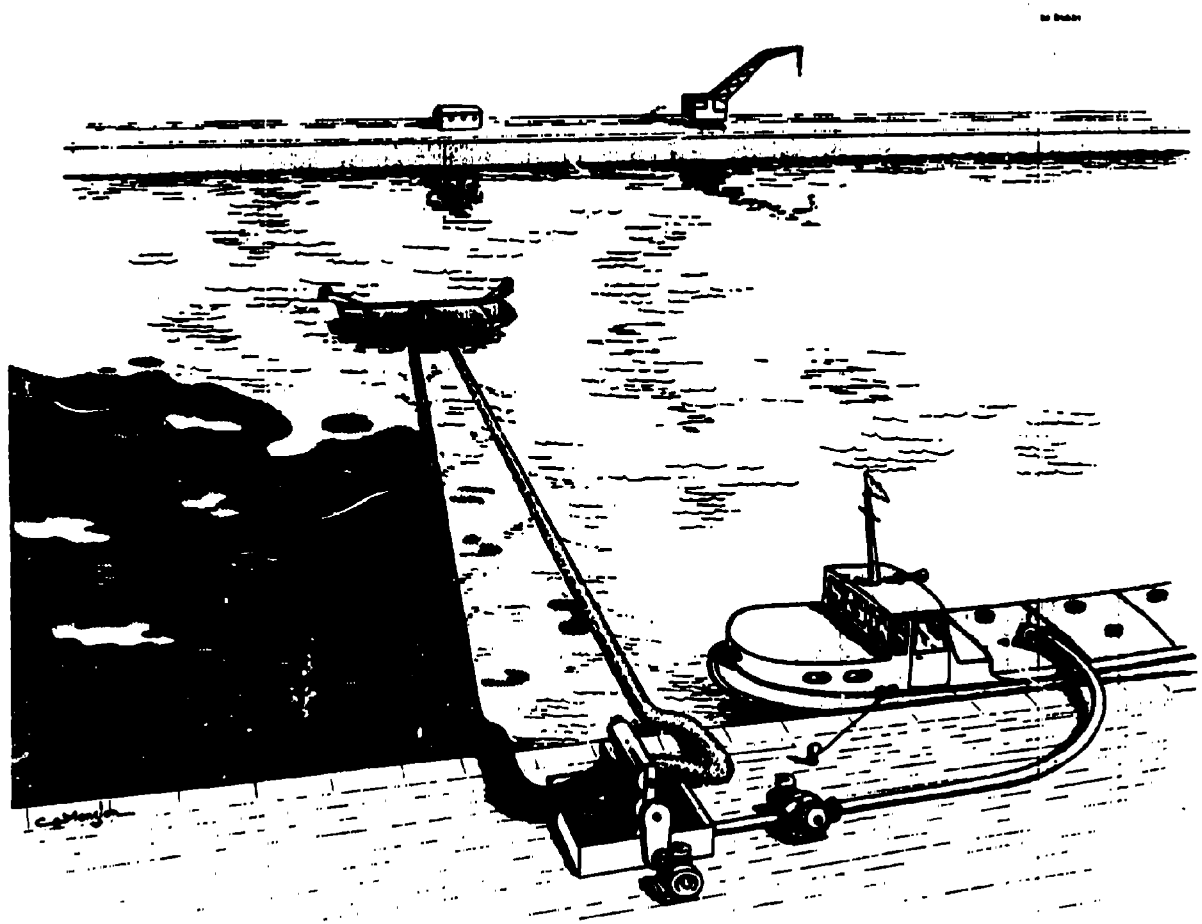


Figure D-27 Oil recovery belt system
Shell Oil Laboratory (Netherlands) and Murpny Pacific Marine Salvage Co.

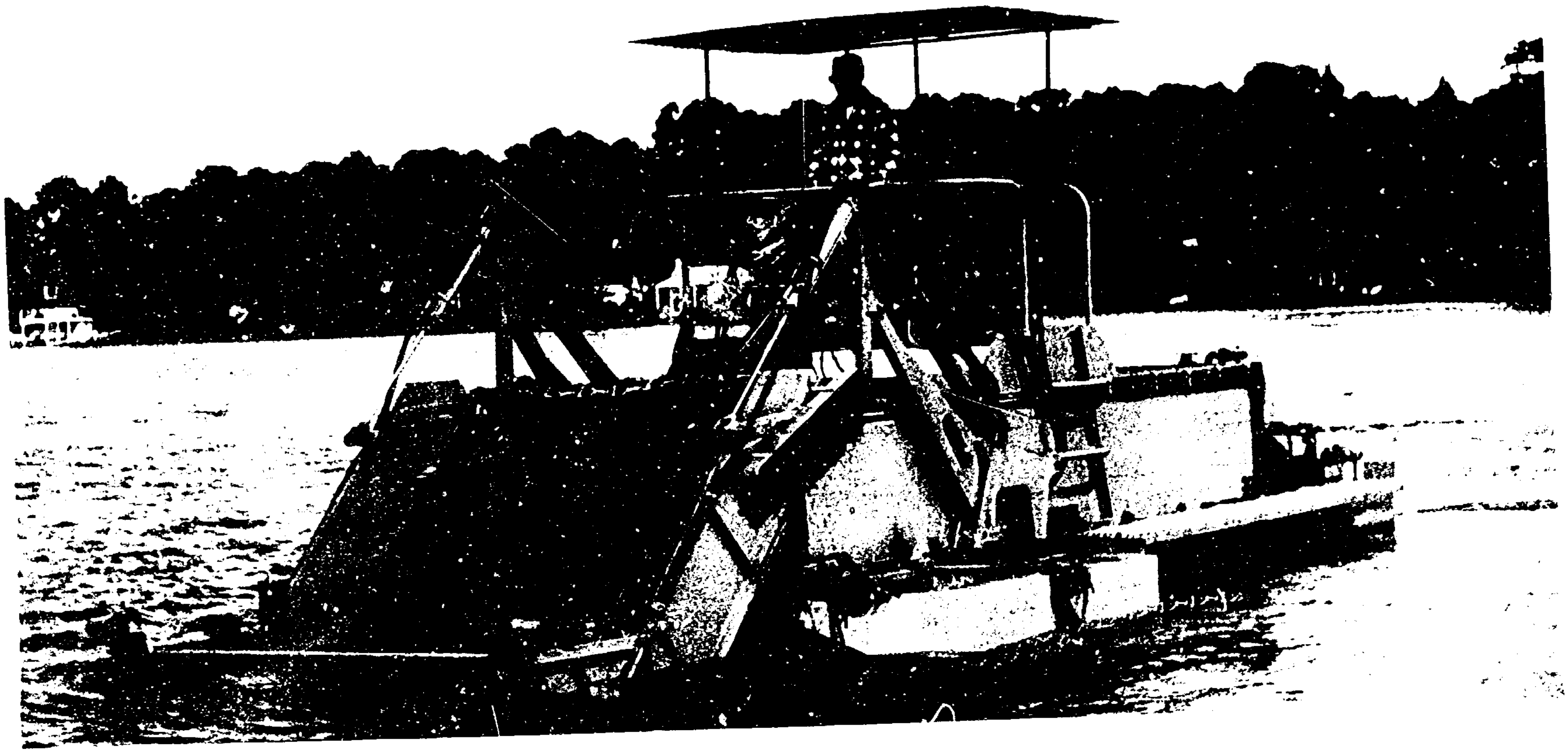


Figure D-28 Marine scavenger model 258-II
produced by Aquatic Controls Corporation

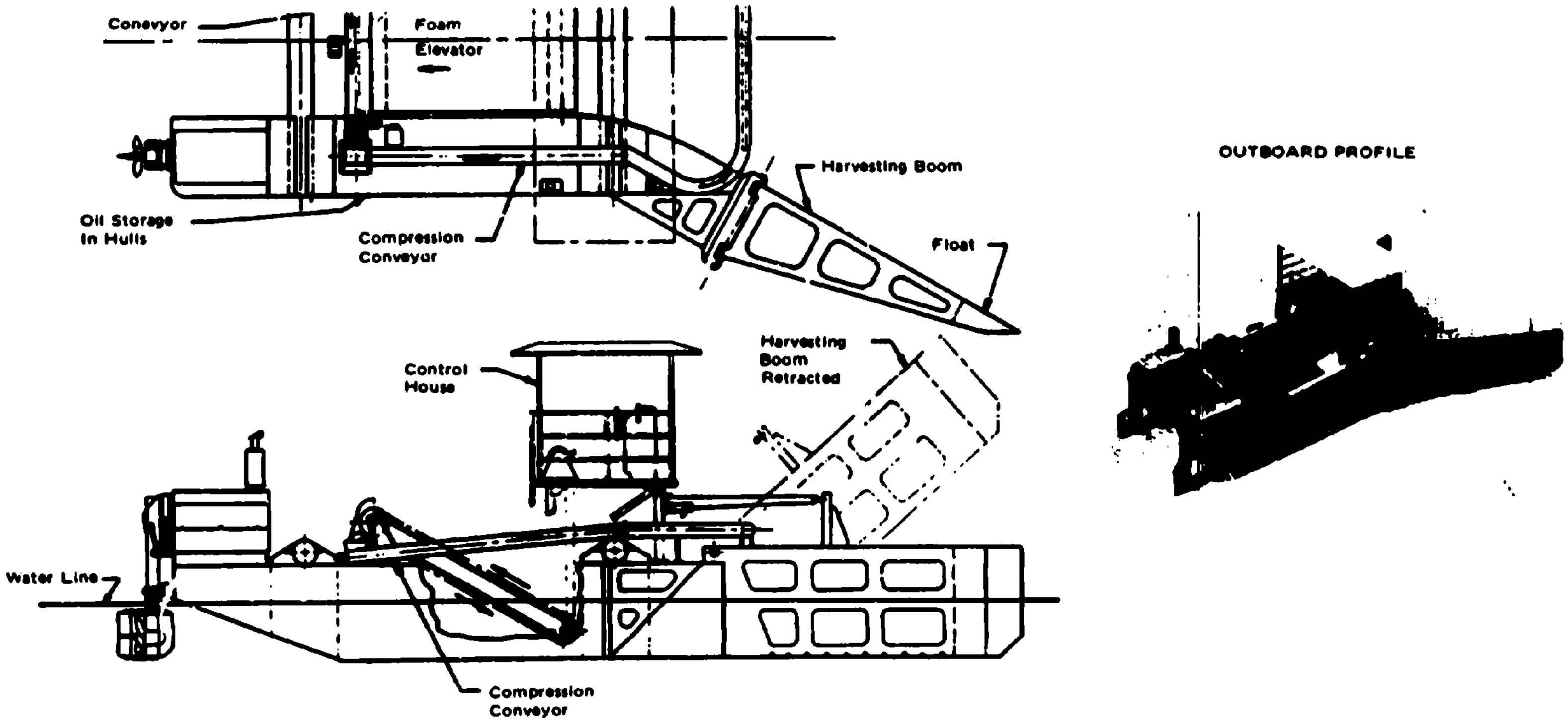
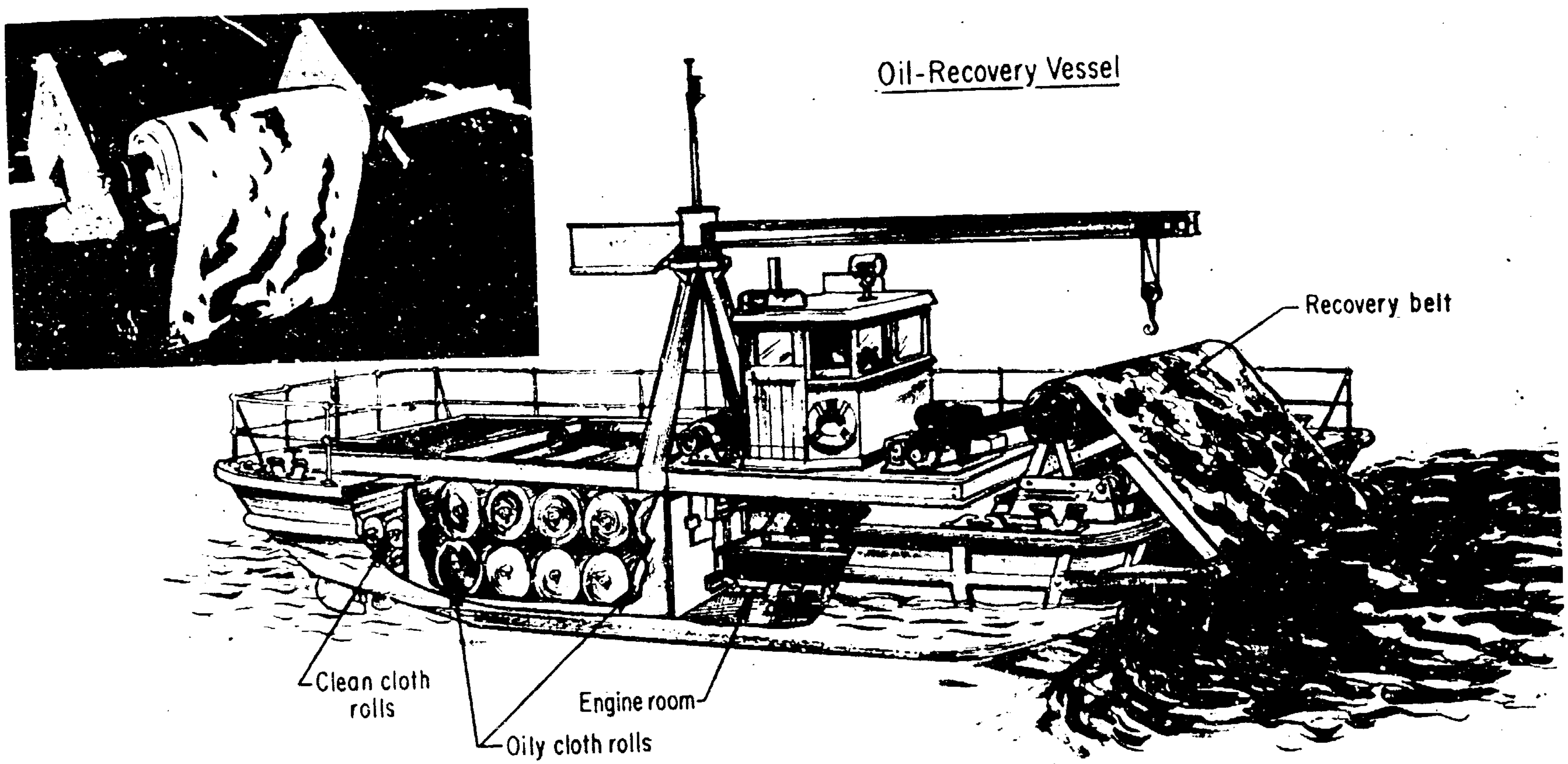



**Figure D-29 Surface oil pickup (SOP)**
**produced by Ocean Design Engineering Corp.**




**Proposed British** vessel would pick up oil film on large cloth rollers (inset).

Figure D-30 Mutton cloth roll skimmer developed by Oswald Hardie, chief engineer, Port of Manchester, England

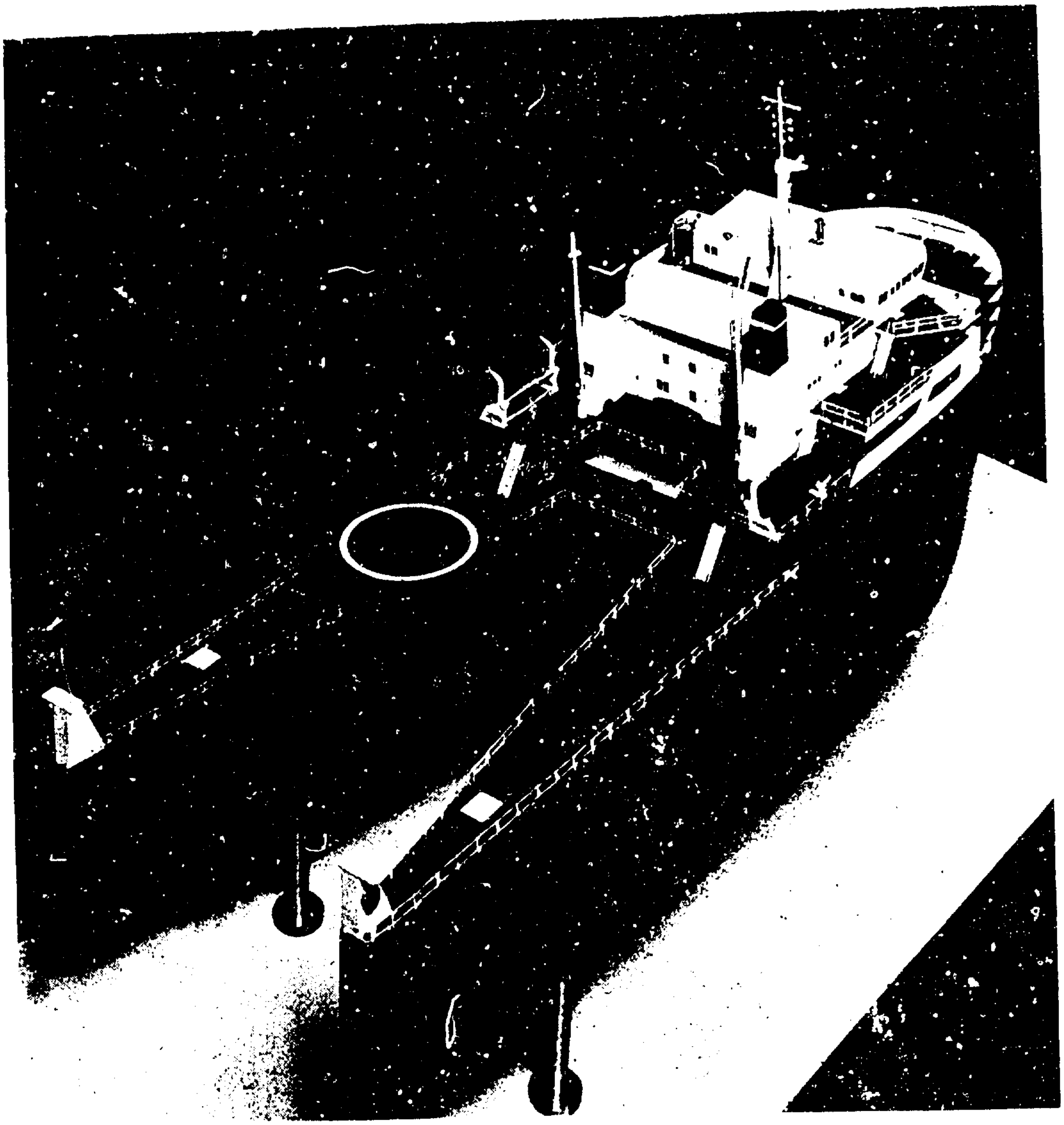


Figure D-31 Spilled oil skimming vessel
a concept of the French Technocean Company

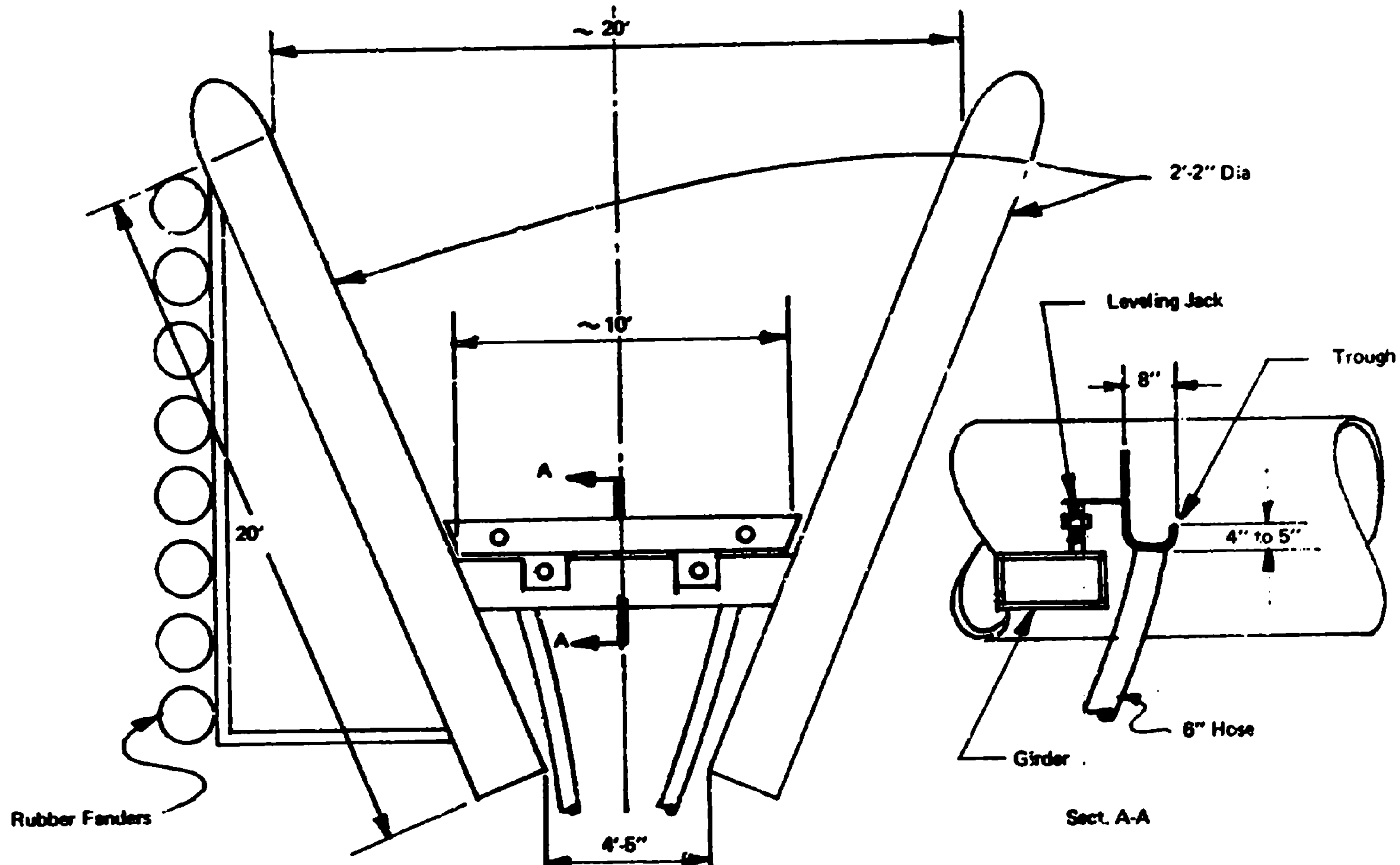



Figure D-32 Open sea skimmer designed by Union Oil Company

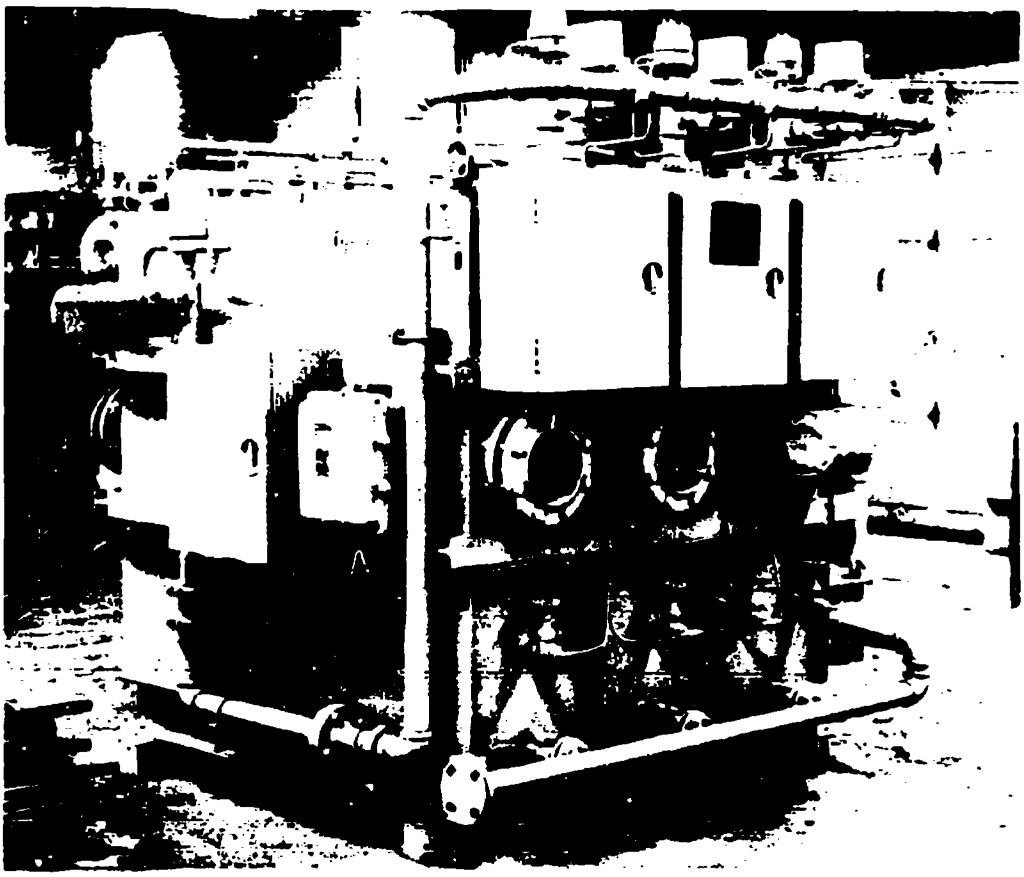

**COALESCENT OIL-WATER separator ready for installation.**

Figure D-33 Coalescent oil-water separator
produced by Aqua-Chem

# APPENDIX E

# EFFECTIVENESS ANAI YSIS WORKSHEETS

## EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM: 1. Chemical Dispersants Applied Directly to Spill

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700 gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

Criteria

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | +2 | +2 | +.5 | +1 | +2 | +1 | +1 | +2 | 11.5 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | 0.5 | | | 11 | |
| | | 2 | | | | | | | | | 11 | |
| | D | 1 | 1 | | | | | | | | 10 | |
| | | 2 | | | | | | | | | 10 | 88 |
| II | A | 1 | 2 | 0 | | | | +1 | | | 9.5 | |
| | | 2 | | 1 | | | | | | | 10.5 | |
| | B | 1 | | 0 | | | | | | | 9.5 | |
| | | 2 | | 1 | | | | | | | 10.5 | |
| | C | 1 | | | | | | 0 | | | 9.5 | |
| | | 2 | | 2 | | | | | | | 10.5 | |
| | D | 1 | 1 | | | | | | | | 9.5 | |
| | | 2 | | | | | | | | | 9.5 | 79 |
| III | A | 1 | 2 | 0 | | | | +1 | 0 | | 8.5 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | 0 | | | 7.5 | |
| | | 2 | | | | | | | | | 7.5 | |
| | D | 1 | | | | | | | | | 6.5 | |
| | | 2 | | | | | | | | | 6.5 | 62 |

TOTAL 229

## EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM: 2, Chemical Dispersants Plus Containment Boom

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700 gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

**Criteria**

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | +2 | +2 | +1 | +.5 | 0 | +1 | +1 | +1 | 8.5 | |
| | | 2 | | | | | | | | | 8.5 | |
| | B | 1 | | | .5 | | | | | | 8 | |
| | | 2 | | | | | | | | | 8 | |
| | C | 1 | | | | | | .5 | | | 7.5 | |
| | | 2 | | | | | | | | | 7.5 | |
| | D | 1 | 1 | | | | | | | | 6.5 | |
| | | 2 | | | | | | | | | 6.5 | 61 |
| II | A | 1 | 2 | 1 | 1 | | | 1 | | | 7.5 | |
| | | 2 | | | | | | | | | 7.5 | |
| | B | 1 | | | .5 | | | | | | 7 | |
| | | 2 | | | | | | | | | 7 | |
| | C | 1 | | | | | | .5 | | | 6.5 | |
| | | 2 | | | | | | | | | 6.5 | |
| | D | 1 | 1 | | | | | | | | 5.5 | |
| | | 2 | | | | | | | | | 5.5 | 53 |
| III | A | 1 | 2 | 0 | 1 | | | 1 | 0 | | 5.5 | |
| | | 2 | | | | | | | | | 5.5 | |
| | B | 1 | | | .5 | | | | | | 5 | |
| | | 2 | | | | | | | | | 5 | |
| | C | 1 | | | | | | .5 | | | 4.5 | |
| | | 2 | | | | | | | | | 4.5 | |
| | D | 1 | 1 | | | | | | | | 3.5 | |
| | | 2 | | | | | | | | | 3.5 | 37 |

TOTAL 151

# EFFECTIVENESS ANALYSIS WORKSHEET

**SYSTEM:** 3. Chemical Burning Agents Applied Directly to Spill

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | |
| | C. Navy Special | |
| III 6,750,000 gal | D. Bunker C | 2. 12 Miles From Shore |

**Criteria**

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | 0 | -1 | 0 | +.5 | 0 | +1 | +1 | +2 | 3.5 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | D | 1 | +1 | +1 | | | | | | | 6.5 | |
| | | 2 | | | | | | | | | 6.5 | 34 |
| II | A | 1 | 0 | -1 | | | | | | | 3.5 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | D | 1 | +1 | +1 | | | | | | | 6.5 | |
| | | 2 | | | | | | | | | | 34 |
| III | A | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | D | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | 52 |

TOTAL 120

# EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM: 3. Chemical Burning Agents Plus Containment Boom (Away from Ship)

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | |
| | C. Navy Special | |
| III 6,750,000 gal | D. Bunker C | 2. 12 Miles From Shore |

**Criteria**

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | 0 | -1 | 0 | .5 | 0 | 1 | 1 | 1 | 2.5 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | D | 1 | +1 | +1 | | | | | | | 5.5 | |
| | | 2 | | | | | | | | | | 26 |
| II | A | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | D | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | 44 |
| III | A | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | D | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | 44 |

TOTAL 114

## EFFECTIVENESS ANALYSIS WORKSHEET

**SYSTEM:** 5. Biological Degrading (exclusive of chemical dispersants) by Addition of Microorganisms

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700 gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

**Criteria**

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | 0 | -1 | +.5 | +.5 | +1 | 0 | +2 | +2 | 5 | |
| I | A | 2 | | | | | | | | | | |
| I | B | 1 | | | | | | | | | | |
| I | B | 2 | | | | | | | | | | |
| I | C | 1 | | | | | | | | | | |
| I | C | 2 | | | | | | | | | | |
| I | D | 1 | | | | | | | | | | |
| I | D | 2 | | | | | | | | | | 40 |
| II | A | 1 | | | | | | | | | | |
| II | A | 2 | | | | | | | | | | |
| II | B | 1 | | | | | | | | | | |
| II | B | 2 | | | | | | | | | | |
| II | C | 1 | | | | | | | | | | |
| II | C | 2 | | | | | | | | | | |
| II | D | 1 | | | | | | | | | | |
| II | D | 2 | | | | | | | | | | 40 |
| III | A | 1 | | | | | | | | | | |
| III | A | 2 | | | | | | | | | | |
| III | B | 1 | | | | | | | | | | |
| III | B | 2 | | | | | | | | | | |
| III | C | 1 | | | | | | | | | | |
| III | C | 2 | | | | | | | | | | |
| III | D | 1 | | | | | | | | | | |
| III | D | 2 | | | | | | | | | | 40 |

TOTAL 120

## EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM: 6. Sorbents/Suction Pump

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700 gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

**Criteria**

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | 0 | +1 | 0 | 0 | 0 | +1 | +2 | +1 | 5 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 4.5 | |
| | | 2 | | | | | | | | | 4.5 | |
| | D | 1 | | 0 | | | | 0 | | | 3 | |
| | | 2 | | | | | | | | | 3 | 35 |
| II | A | 1 | | | | | | +1 | | | 4 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 3.5 | |
| | | 2 | | | | | | | | | 3.5 | |
| | D | 1 | | -1 | | | | 0 | | | 2 | |
| | | 2 | | | | | | | | | 2 | 27 |
| III | A | 1 | | | | | | +1 | | | 3 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 2.5 | |
| | | 2 | | | | | | | | | 2.5 | |
| | D | 1 | | | | | | 0 | | | 2 | |
| | | 2 | | | | | | | | | 2 | 21 |

TOTAL, 83

## EFFECTIVENESS ANALYSIS WORKSHEET

**SYSTEM:** 7. Sorbents/Suction Pump plus Containment Boom

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

**Criteria**

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | +1 | +2 | 0 | 0 | 0 | +1 | +2 | 0 | 6 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 5.5 | |
| | | 2 | | | | | | | | | 5.5 | |
| | D | 1 | 0 | +1 | | | | 0 | | | 3 | |
| | | 2 | | | | | | | | | 3 | 41 |
| II | A | 1 | +1 | | | | | +1 | | | 5 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 4.5 | |
| | | 2 | | | | | | | | | 4.5 | |
| | D | 1 | 0 | 0 | | | | 0 | | | 2 | |
| | | 2 | | | | | | | | | 2 | 33 |
| III | A | 1 | +1 | -1 | | | | +1 | | | 3 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 2.5 | |
| | | 2 | | | | | | | | | 2.5 | |
| | D | 1 | | | | | | 0 | | | 1 | |
| | | 2 | | | | | | | | | 1 | 19 |

TOTAL 93

## EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM: 8. Sorbents/Conveyor

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

**Criteria**

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | 0 | +1 | 0 | 0 | +1 | +1 | +2 | +1 | 6 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 5.5 | |
| | | 2 | | | | | | | | | 5.5 | |
| | D | 1 | | 0 | | | | 0 | | | 4 | |
| | | 2 | | | | | | | | | 4 | 43 |
| II | A | 1 | | | | | | +1 | | | 5 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 4.5 | |
| | | 2 | | | | | | | | | 4.5 | |
| | D | 1 | | -1 | | | | 0 | | | 3 | |
| | | 2 | | | | | | | | | 3 | 35 |
| III | A | 1 | | | | | | +1 | | | 4 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 3.5 | |
| | | 2 | | | | | | | | | 3.5 | |
| | D | 1 | | | | | | 0 | | | 3 | |
| | | 2 | | | | | | | | | 3 | 29 |

TOTAL 107

## EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM: 9. Sorbents/Conveyor plus Containment Boom

Parameters

| Size | Products | Location |
|---|---|---|
| I 2700 gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

Criteria

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | +1 | +2 | 0 | 0 | 0 | +1 | +2 | 0 | 6 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 5.5 | |
| | | 2 | | | | | | | | | 5.5 | |
| | D | 1 | 0 | -1 | | | | 0 | | | 3 | |
| | | 2 | | | | | | | | | 3 | 41 |
| II | A | 1 | +1 | | | | | +1 | | | 5 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 4.5 | |
| | | 2 | | | | | | | | | 4.5 | |
| | D | 1 | 0 | -1 | | | | 0 | | | 1 | |
| | | 2 | | | | | | | | | 1 | 31 |
| III | A | 1 | +1 | | | | | +1 | | | 3 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 2.5 | |
| | | 2 | | | | | | | | | 2.5 | |
| | D | 1 | 0 | | | | | 0 | | | 1 | |
| | | 2 | | | | | | | | | 1 | 19 |

TOTAL 91

## EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM 10. Gellants/Conveyer

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700 gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III a 750,000 gal | C. Navy Special | |
| | D. Bunker C | |

**Criteria**

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | 0 | +1 | .5 | 0 | +1 | +1 | +2 | +1 | 6.5 | |
| I | A | 2 | | | | | | | | | | |
| I | B | 1 | | | | | | | | | | |
| I | B | 2 | | | | | | | | | | |
| I | C | 1 | | | | | | | | | | |
| I | C | 2 | | | | | | | | | | |
| I | D | 1 | | | | | | | | | | |
| I | D | 2 | | | | | | | | | | 52 |
| II | A | 1 | | 0 | | | | | | | 5.5 | |
| II | A | 2 | | | | | | | | | | |
| II | B | 1 | | | | | | | | | | |
| II | B | 2 | | | | | | | | | | |
| II | C | 1 | | | | | | | | | | |
| II | C | 2 | | | | | | | | | | |
| II | D | 1 | | | | | | | | | | |
| II | D | 2 | | | | | | | | | | 44 |
| III | A | 1 | | -1 | | | | | | | 4.5 | |
| III | A | 2 | | | | | | | | | | |
| III | B | 1 | | | | | | | | | | |
| III | B | 2 | | | | | | | | | | |
| III | C | 1 | | | | | | | | | | |
| III | C | 2 | | | | | | | | | | |
| III | D | 1 | | | | | | | | | | |
| III | D | 2 | | | | | | | | | | 36 |

TOTAL 132

## EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM: 11. Gellants/Conveyor Plus Containment Boom

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700 gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

Criteria

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | +1 | +1 | +.5 | 0 | 0 | +1 | +2 | 0 | 5.5 | |
| I | A | 2 | | | | | | | | | | |
| I | B | 1 | | | | | | | | | | |
| I | B | 2 | | | | | | | | | | |
| I | C | 1 | | | | | | | | | | |
| I | C | 2 | | | | | | | | | | |
| I | D | 1 | | | | | | | | | | |
| I | D | 2 | | | | | | | | | | 44 |
| II | A | 1 | | | | | | | | | | |
| II | A | 2 | | | | | | | | | | |
| II | B | 1 | | | | | | | | | | |
| II | B | 2 | | | | | | | | | | |
| II | C | 1 | | | | | | | | | | |
| II | C | 2 | | | | | | | | | | |
| II | D | 1 | | | | | | | | | | |
| II | D | 2 | | | | | | | | | | 44 |
| III | A | 1 | | 0 | | | | | | | 4.5 | |
| III | A | 2 | | | | | | | | | | |
| III | B | 1 | | | | | | | | | | |
| III | B | 2 | | | | | | | | | | |
| III | C | 1 | | | | | | | | | | |
| III | C | 2 | | | | | | | | | | |
| III | D | 1 | | | | | | | | | | |
| III | D | 2 | | | | | | | | | | 36 |

TOTAL 124

## EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM 12. Sinking Agents Applied Directly to the Spill

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700 gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

**Criteria**

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | 0 | 0 | 0 | .5 | 0 | +1 | 0 | +1 | 2.5 | |
| | | 2 | | | | | | | +1 | | 3.5 | |
| | B | 1 | | | | | | | 0 | | 2.5 | |
| | | 2 | | | | | | | +1 | | 3.5 | |
| | C | 1 | +1 | +1 | | | | | 0 | | 4.5 | |
| | | 2 | | | | | | | +1 | | [illegible] | |
| | D | 1 | | | | | | | 0 | | 4.5 | |
| | | 2 | | | | | | | +1 | | 5.5 | 32 |
| II | A | 1 | 0 | 0 | | | | | 0 | | 2.5 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | +1 | +1 | | | | | | | 4.5 | |
| | | 2 | | 0 | | | | | | | 3.5 | |
| | D | 1 | | +1 | | | | | | | 4.5 | |
| | | 2 | | 0 | | | | | | | 3.5 | 26 |
| III | A | 1 | 0 | | | | | | | | 2.5 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | +1 | | | | | | | | 3.5 | |
| | | 2 | | | | | | | | | | |
| | D | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | 24 |

TOTAL 82

## EFFECTIVENESS ANALYSIS WORKSHEET

**SYSTEM:** 13. Sinking Agents Plus Containment Boom

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700 gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

**Criteria**

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | +1 | +2 | 0 | 0 | 0 | +1 | 0 | 0 | 4 | |
| | | 2 | | | | | | | +1 | | 5 | |
| | B | 1 | | | | | | | 0 | | 4 | |
| | | 2 | | | | | | | +1 | | 5 | |
| | C | 1 | | | | | | | 0 | | 4 | |
| | | 2 | | | | | | | +1 | | 5 | |
| | D | 1 | | | | | | | 0 | | 4 | |
| | | 2 | | | | | | | +1 | | 5 | 36 |
| II | A | 1 | | +1 | | | | | 0 | | 3 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | D | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | 24 |
| III | A | 1 | | 0 | | | | | | | 2 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | D | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | 16 |

TOTAL 76

# EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM. 11. Rotating Drums

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700 gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

**Criteria**

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | 0 | -1 | +1 | 0 | 0 | +1 | +2 | 0 | 3 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 2.5 | |
| | | 2 | | | | | | | | | | |
| | D | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | 22 |
| II | A | 1 | | | | | | +1 | | | 3 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 2.5 | |
| | | 2 | | | | | | | | | | |
| | D | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | 22 |
| III | A | 1 | | | | | | +1 | | | 3 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 2.5 | |
| | | 2 | | | | | | | | | | |
| | D | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | 22 |

TOTAL 66

## EFFECTIVENESS ANALYSIS WORKSHEET

**SYSTEM:** 15. Rotating Drums Plus Containment Boom

Parameters

| Size | Products | Location |
|---|---|---|
| I 2700 gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

Criteria

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | 0 | -1 | +1 | 0 | 0 | +1 | +2 | 0 | 3 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 2.5 | |
| | | 2 | | | | | | | | | | |
| | D | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | 22 |
| II | A | 1 | | | | | | +1 | | | 3 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 2.5 | |
| | | 2 | | | | | | | | | | |
| | D | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | 22 |
| III | A | 1 | | | | | | +1 | | | 3 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 2.5 | |
| | | 2 | | | | | | | | | | |
| | D | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | 22 |

TOTAL 66

# EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM: 16. Endless Belt on Water Surface

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700 gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

**Criteria**

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | 0 | 0 | +1 | 0 | +1 | +1 | +2 | 0 | 5 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 4.5 | |
| | | 2 | | 1 | | | | | | | 5.5 | |
| | D | 1 | | | | | | 0 | | | 5 | |
| | | 2 | | | | | | | | | | 40 |
| II | A | 1 | | 0 | | | | +1 | | | | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 4.5 | |
| | | 2 | | | | | | | | | 4.5 | |
| | D | 1 | | | | | | 0 | | | 4 | |
| | | 2 | | | | | | | | | | 37 |
| III | A | 1 | | -1 | | | | +1 | | | | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 3.5 | |
| | | 2 | | | | | | | | | 3.5 | |
| | D | 1 | | | | | | 0 | | | 3 | |
| | | 2 | | | | | | | | | 3 | 29 |

TOTAL 106

# EFFECTIVENESS ANALYSIS WORKSHEET

**SYSTEM:** 17. Endless Belt Plus Containment Boom

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | |
| | C. Navy Special | |
| III 6,750,000 gal | D. Bunker C | 2. 12 Miles From Shore |

**Criteria**

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | 0 | +1 | +1 | 0 | 0 | +1 | +2 | 0 | 5 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 4.5 | |
| | | 2 | | | | | | | | | 4.5 | |
| | D | 1 | | | | | | 0 | | | 4 | |
| | | 2 | | | | | | | | | | 37 |
| II | A | 1 | | 0 | | | | +1 | | | | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 3.5 | |
| | | 2 | | | | | | | | | 3.5 | |
| | D | 1 | | | | | | 0 | | | 3 | |
| | | 2 | | | | | | | | | | 29 |
| III | A | 1 | | -1 | | | | +1 | | | | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 2.5 | |
| | | 2 | | | | | | | | | 2.5 | |
| | D | 1 | | | | | | 0 | | | 2 | |
| | | 2 | | | | | | | | | 2 | 21 |

TOTAL 87

EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM: 18. Suction Devices

Parameters

| Size | Products | Location |
|---|---|---|
| I 2700 gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

Criteria

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | 0 | -1 | +1 | 0 | 0 | +1 | +2 | +1 | 4 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 3.5 | |
| | | 2 | | | | | | | | | 3.5 | |
| | D | 1 | | | | | | 0 | | | 3 | |
| | | 2 | | | | | | | | | 3 | 29 |
| II | A | 1 | | | | | | +1 | | | 4 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 3.5 | |
| | | 2 | | | | | | | | | 3.5 | |
| | D | 1 | | | | | | 0 | | | 3 | |
| | | 2 | | | | | | | | | 3 | 29 |
| III | A | 1 | | | | | | +1 | | | 4 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 3.5 | |
| | | 2 | | | | | | | | | 3.5 | |
| | D | 1 | | | | | | 0 | | | 3 | |
| | | 2 | | | | | | | | | 3 | 29 |

TOTAL 87

## EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM: 19. Suction Devices Plus Containment Boom

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700 gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

Criteria

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | 0 | -1 | +1 | 0 | 0 | +1 | +2 | 0 | 3 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 2.5 | |
| | | 2 | | | | | | | | | 2.5 | |
| | D | 1 | | | | | | 0 | | | 2 | |
| | | 2 | | | | | | | | | 2 | 21 |
| II | A | 1 | | | | | | +1 | | | 3 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 2.5 | |
| | | 2 | | | | | | | | | 2.5 | |
| | D | 1 | | | | | | 0 | | | 2 | |
| | | 2 | | | | | | | | | 2 | 21 |
| III | A | 1 | | | | | | +1 | | | 3 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 2.5 | |
| | | 2 | | | | | | | | | 2.5 | |
| | D | 1 | | | | | | 0 | | | 2 | |
| | | 2 | | | | | | | | | 2 | 21 |

TOTAL 63

## EFFECTIVENESS ANALYSIS WORKSHEET

SYSTEM 20. Advancing Skimmer or Weir

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700 gal | A JP 5 | 1. 3 Miles From Shore |
| II 270,000 gal | B Distillate | 2. 12 Miles From Shore |
| III 6 750,000 gal | C Navy Special | |
| | D Bunker C | |

**Criteria**

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Use in Lim. Access | Sens. to Envir. Factors | Sens. to Temp | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | +1 | +1 | +1 | +.0 | 0 | +1 | +2 | +1 | 7.0 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | +2 | | | | 0 | | | 8 | |
| | | 2 | | | | | | | | | 8 | |
| | D | 1 | 0 | 0 | | | | 0 | | | 4.0 | |
| | | 2 | | | | | | | | | 4.0 | [illegible] |
| II | A | 1 | +1 | +1 | | | | +1 | | | [illegible] | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | 0 | | | [illegible] | |
| | | 2 | | | | | | | | | [illegible] | |
| | D | 1 | 0 | | | | | 0 | | | [illegible] | |
| | | 2 | | | | | | | | | [illegible] | [illegible] |
| III | A | 1 | +1 | | | | | +1 | | | [illegible] | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | 0 | | | [illegible] | |
| | | 2 | | | | | | | | | [illegible] | |
| | D | 1 | 0 | | | | | 0 | | | [illegible] | |
| | | 2 | | | | | | | | | [illegible] | [illegible] |

TOTAL [illegible]

# EFFECTIVENESS ANALYSIS WORKSHEET

**SYSTEM:** 21. Advancing Skimmer or Weir Plus Containment Boom

**Parameters**

| Size | Products | Location |
|---|---|---|
| I 2700 gal | A. JP-5 | 1. 3 Miles From Shore |
| II 270,000 gal | B. Distillate | 2. 12 Miles From Shore |
| III 6,750,000 gal | C. Navy Special | |
| | D. Bunker C | |

Criteria

| Size | Product | Location | Completeness | Rate of Removal | Hazard & Poll | Ease in Lim. Access | Sens. to Envir. Factors | Sens. to Temp. | Toxicity | Availability | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | A | 1 | +1 | +2 | -1 | 0 | 0 | +1 | +2 | 0 | [illegible] | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | .5 | | | 6.5 | |
| | | 2 | | | | | | | | | 0.5 | |
| | D | 1 | 0 | 1 | | | | 0 | | | 1 | |
| | | 2 | | | | | | | | | 1 | 10 |
| II | A | 1 | +1 | 0 | | | | 1 | | | 5 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | 1.0 | | | 1.0 | |
| | | 2 | | | | | | | | | 1.5 | |
| | D | 1 | 0 | -1 | | | | 0 | | | 2 | |
| | | 2 | | | | | | | | | 2 | [illegible] |
| III | A | 1 | 1 | | | | | 1 | | | 1 | |
| | | 2 | | | | | | | | | | |
| | B | 1 | | | | | | | | | | |
| | | 2 | | | | | | | | | | |
| | C | 1 | | | | | | 1.0 | | | 3.0 | |
| | | 2 | | | | | | | | | [illegible] | |
| | D | 1 | 0 | | | | | 0 | | | 2 | |
| | | 2 | | | | | | | | | 2 | 27 |

TOTAL 100

# APPENDIX F

## SCHEDULE OF DISPERSANTS AND OTHER CHEMICALS TO TREAT OIL SPILLS

## APPENDIX F

The following, Annex X of the National Oil and Hazardous Materials Pollution Contingency Plan, June 1970, are the Federal Water Quality Administration recommendations on the use of dispersants, sinking agents and collecting agents:

### ANNEX X

2000 SCHEDULE OF DISPERSANTS AND OTHER CHEMICALS TO TREAT OIL SPILLS

2001 GENERAL

2001.1 This schedule shall apply to the navigable waters of the United States and adjoining shorelines, and the waters of the contiguous zone as defined in Article 24 of the Convention on the Territorial Sea and the Contiguous Zone.

2001.2 This schedule applies to the regulation of any chemical as hereinafter defined that is applied to an oil spill.

2001.3 This schedule advocates development and utilization of mechanical and other control methods that will result in removal of oil from the environment with subsequent proper disposal.

2001.4 Relationship of the Federal Water Quality Administration (FWQA) with other Federal agencies and State agencies in implementing this schedule: In those States with more stringent laws, regulations or written policies for regulation of chemical use, such State laws, regulations or written policies shall govern. This schedule will apply in those States that have not adopted such laws, regulations or written policies.

2002 DEFINITIONS. Substances applied to an oil spill are defined as follows:

2002.1 Collecting agents - includes chemicals or other agents that can gell, sorb, congeal, herd, entrap, fix, or make the oil mass more rigid or viscous in order to facilitate surface removal of oil.

2002.2 Sinking Agents - are those chemical or other agents that can physically sink oil below the water surface.

2002.3 Dispersing agents - are those chemical agents or compounds which emulsify, disperse or solubilize oil into the water column or act to further the surface spreading of oil slicks in order to facilitate dispersal of the oil into the water column.

2003 COLLECTING AGENTS. Considered to be generally acceptable providing that these materials do not in themselves or in combination with the oil increase the pollution hazard.

2004 SINKING AGENTS. Sinking agents may be used only in marine waters exceeding 100 meters in depth where currents are not predominately onshore, and only if other control methods are judged by FWQA to be indequate or not feasible.

2005 AUTHORITIES CONTROLLING USE OF DISPERSANTS

2005.1 Regional response team activated: Dispersants may be used in any place, at any time, and in quantities designated by the On-Scene Commander, when their use will:

2005.1-1 In the judgment of the On-Scene Commander, prevent or substantially reduce hazard to human life or limb or substantial hazard of fire to property.

2005.1-2 In the judgment of FWQA, in consultation with appropriate State agencies, prevent or reduce substantial hazard to a major segment of the population(s) of vulnerable species of waterfowl.

2005.1-3 In the judgment of FWQA, in consultation with appropriate State agencies, result in the least overall environmental damage or interference with designated uses.

2005.2 Regional response team not activated: Provisions of Section 2005.1-1 shall apply. The use of dispersants in any other situation shall be subject to this schedule except in States where State laws, regulations, or written policies are in effect that govern the prohibition, use, quantity, or type of dispersant. In such States, the State laws, regulations or written policies shall be followed during the clean up operation.

2006 INTERIM RESTRICTIONS ON USE OF DISPERSANTS FOR POLLUTION CONTROL PURPOSES: Except as noted in 2005.1, dispersants shall not be used:

2006.1 on any distillate fuel oil.

2006.2 on any spill of oil less than 200 barrels in quantity.

2006.3 on any shoreline.

2006.4 in any waters less than 100 feet deep.

2006.5 in any waters containing major populations, or breeding or passage areas for species of fish or marine life which may be damaged or rendered commercially less marketable by exposure to dispersant or dispersed oil.

2006.6 in any waters where winds and/or currents are of such velocity and direction that dispersed oil mixtures would likely, in the judgment of FWQA, be carried to shore areas within 24 hours.

2006.7 in any waters where such use may affect surface water supplies.

2007 DISPERSANT USE. Dispersants may be used in accordance with this schedule if other control methods are judged to be inadequate or infeasible, and if:

2007.1 Information has been provided to FWQA, in sufficient time prior to its use for review by FWQA, on its toxicity, effectiveness and oxygen demand determined by the standard procedures published by FWQA. [Prior to publication by FWQA of standard procedures, no dispersant shall be applied, except as noted in Section 2005.1-1 in quantities exceeding 5 ppm in the upper three feet of the water column during any 24-hour period. This amount is equivalent to 5 gallons per acre per 24 hours.]

2007.2 Applied during any 24-hour period in quantities not exceeding the 96 hour $TL_{50}$ of the most sensitive species tested as calculated in the top foot of the water column. The maximum volume of chemical permitted, in gallons per acre per 24 hours, shall be calculated by multiplying the 96 hour $TL_{50}$ value of the most sensitive species tested, in ppm, by 0.33; except that in no case, except as noted in Section 2005.1-1, will the daily application rate of chemical exceed 540 gallons per acre or one-fifth of the total volume spilled, whichever quantity is smaller.

2007.3 Dispersant containers are labeled with the following information:

2007.3-1 Name, brand or trademark, if any, under which the chemical is sold.

2007.3-2 Name and address of the manufacturer, importer or vendor.

2007.3-3 Flash point.

2007.3-4 Freezing or pour point.

2007.3-5 Viscosity.

2007.3-6 Recommend application procedure(s), concentration(s), and conditions

for use as regards water salinity, water temperature, and types and ages of oils.

2007.3-7 Date of production and shelf life.

2007.4 Information to be supplied to FWQA on the:

2007.4-1 Chemical name and percentage of each component.

2007.4-2 Concentrations of potentially hazardous trace materials, including, but not necessarily being limited to: lead, chromium, zinc, arsenic, mercury, nickel, copper and chlorinated hydrocarbons.

2007.4-3 Description of analytical methods used in determining chemical characteristics outlined in 2007.4-1,2 above.

2007.4-4 Methods for analyzing the chemical in fresh and salt water are provided to FWQA, or reasons why such analytical methods cannot be provided.

2007.4-5 For purposes of research and development, FWQA may authorize use of dispersants in specified amounts and locations under controlled conditions irrespective of the provisions of this schedule.

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13. ABSTRACT

A cost effectiveness analysis was performed for equipment, materials and techniques applicable to the removal or dispersal of spilled oil from U.S. Navy AO and AOG vessels on open waters. Effectiveness parameters included oil product types (JP-5, Distillate Fuel, Navy Special and Bunker C), expected spill locations (3 and 12 miles from shore) and size of expected spill (10 tons, 1000 tons and 25,000 tons). Criteria for evaluation of systems under the above parameter situations, formulated for presently available equipment and materials, include: completeness of oil removal; rate of removal; hazard and pollution; use in limited access areas; sensitivicy to expected environmental factors; sensitivity to temperature extremes; toxicity to marine life and system availability. Cost effectiveness was determined using the 3 spill sizes and checked for spill frequency sensitivity. The three most cost effective systems for the spectrum of spill sizes were found to be burning of the oil, dispersing the spilled oil and mechanical skimming. Considering system applicability to various products and the practical requirements of rate of removal for massive spills, the most practical universal system with a favorable cost effectiveness ratio was found to be dispersing. This is followed by dispersing plus a containment boom. Burning agents applied directly to the spill was judged to be the third system based on its favorable cost effectiveness but limited applicability to oil types and permissible burning circumstances.

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